Elodea – Hydrophyte
Bean
Coleus > Mesophyte
Tulse
Magenta > Xerophytes

LARCH AND BUR OAK, SHOWING TWO TYPES OF MONOPODIAL BRANCHING.

Frontispiece. (*See p.* 87.)

PLANT LIFE

CONSIDERED WITH SPECIAL REFERENCE TO FORM AND FUNCTION

BY

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PREFACE.

In recognition of the fact that the study of botany in the past has been too much a study of books about plants, numerous laboratory manuals have been published which make possible the study of plants themselves. Laboratory work has now become well-nigh universal. With the strenuous insistence that this method should be used in the secondary schools, there has been a growing danger that such study would degenerate into mere memory training, unless the relation of the facts, often entirely isolated in the pupil's mind, were clearly brought out. Since laboratory study soon came to include the examination of the lower plants as well as seed plants, and has now begun to include some experiments in their physiology, the absence of an elementary account of the form and functions of plants of all groups has made itself felt. I am not aware that any book at present attempts to meet this need.

To the proper teaching of botany in secondary schools such a book is indispensable. However capable the teacher may be to gather up the facts observed in the laboratory and to relate them with others so as to produce a clear conception of plant life, he cannot wisely rely upon the lecture for pupils of 13 to 18 years. They need the printed page, which appeals to eye as well as ear, if the principles and facts are to be firmly grasped.

PLANT LIFE is an attempt to exhibit the variety and progressive complexity of the vegetative body; to discuss the more important functions; to explain the unity of plan in both the structure and action of the reproductive organs; and finally to give an outline of the more striking ways in which plants adapt themselves to the world about them. I have made an effort to treat these subjects so that, however much the student may have still to learn, he will have little to unlearn; for eradication of false notions is the despair of the college teacher of science.

This is not a book to be memorized and recited. If so used it is abused. It aims to be intelligible to pupils 13 to 18 years of age who are engaged in genuine laboratory study—not at irregular hours, without supervision, in a school desk, or at home, but in a suitable laboratory, with regular time (an hour and a half daily if possible), under the direction of a live teacher who has studied far more botany than he is trying to teach. I am aware that such conditions are yet unrealized in many schools; but they may be gradually reached. That PLANT LIFE may prove useful in botanical instruction even under the most unfavorable conditions, I permit myself to hope rather than to expect.

This book may be used to supplement any laboratory guide or the directions prepared by the teacher. For the sake of teachers who may not wish to use two books, or who lack time and facilities for preparing laboratory directions, I have outlined a course of study in Appendix I which can be carried out with the equipment listed in Appendix III. A description of the material needed and of suitable methods of preserving it forms Appendix II. Each teacher will, of course, need to modify the directions to suit the material available. I have always found it easier to prepare directions to fit the material than to create the material to fit the directions. The "demonstrations" of Appendix I are intended as suggestions to the

teacher of things which it is advisable to show to pupils under the compound microscope, in case inadequate equipment, lack of time, or difficulty of preparation forbid class study.

I have made the directions fullest in relation to cryptogams and physiology because these fields are most unfamiliar to teachers at present. Further directions for the study of seed plants can readily be provided from the books listed in Appendix IV.

For laboratory study it is necessary to select certain illustrative types and observe their structure. In the text I have not specifically discussed these plants, but have treated general topics so as to correlate the facts gained by a study of types with others which can be readily interpreted by means of the experience in the laboratory. References from the bare directions of Appendix I to the paragraphs and figures of the text are abundant and are intended to aid the student in the comprehension of the type under observation. It may be objected that he is thus aided too much. But I believe that in his first steps in laboratory training the student requires a large amount of help, and that its results are more often nullified by too little assistance than by too much.

In the text I have neither sought nor avoided the use of technical terms. I *have* refrained from making the book a mere illustrated glossary. Yet I see no advantage, even for young students, in repeated circumlocution, for which a single word might stand. Definitions of most of the technical terms used may be found by means of the index; others are defined in the standard dictionaries. The careful teacher will insist upon a clear understanding of the meaning of terms and the accurate use of language.

I have refrained from frequent citation of plants by name as examples of facts stated, chiefly because beginners are rarely familiar with any plants except the commonest domesticated ones and a few forest or shade trees.

No apology is necessary for the exclusive use of the metric system. If pupils lack familiarity with it, the actual handling of metric measures and weights will soon remedy this. A useful chart showing the units may be obtained of the American Metrological Society, 41 East Forty-ninth Street, New York, for ten cents.

Very few of the illustrations are original. In the main they have been selected from a wide range of standard works with especial care to secure accuracy and clearness. Whenever possible the source of the figure and its magnification have been given. The attention of the teacher is invited to the very full description which accompanies each figure. In these explanations will be found much matter which is often put into subordinate paragraphs in other books. I have observed that students are prone merely to "look at" figures, and rarely study them. I therefore suggest that real study of the illustrations as supplementing the text be insisted upon. Sections are apt to be puzzling to beginners unless they are taught how to interpret them. This can be done by requiring them to sketch on paper or blackboard imaginary sections of common objects in different planes. Articles of regular form, such as a pencil, book, slate, ink bottle, desk, etc., may be "sectioned," until from sketches of sections in three planes at right angles the student can construct a mental image of the object.

Although divided into four parts, it has not been possible to keep the subject matter of each wholly distinct, since morphology, physiology and ecology are so interrelated. Indeed it has been thought best to combine the morphology and physiology of the reproductive organs to form Part III, rather than to divide it between two. The teacher will do well to see that the pupil does not neglect the abundant cross references.

While the whole book is simply a restatement of widely

known facts, for which I am mainly indebted to general treatises, monographs and shorter papers, I am constrained to acknowledge for Part IV my special indebtedness to Warming's *Lehrbuch der ökologischen Pflanzengeographie* and Ludwig's *Lehrbuch der Pflanzenbiologie.*

C. R. B.

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PLANT LIFE.

PART I: THE PLANT BODY.

INTRODUCTION.

1. Units of structure.—An examination of any plant by proper methods reveals the fact that it is made up of one or more *units of structure*. The unit of structure of a brick wall is the individual brick. Each has a definite shape and relation to others, upon which the form of the wall depends. The unit of structure of a plant is called a cell. The cells have each a definite form and relation to others, and upon these two factors the form of the entire plant depends.

But between the plant and the brick wall there is this *important difference*. The bricks, after being perfectly formed, *were put together*. The cells of the plant *are produced where they lie and gradually grow to a mature form and size*. The bricks are originally disconnected; the plant-cells are connected by origin, and only as they become mature do they separate, if at all.

2. The cell.—A plant-cell is a minute portion of living matter, called *protoplasm* or *plasma*, generally surrounded by a membrane, called the *cell-wall* (fig. 1). If the brick in the previous illustration be taken to represent the protoplasm, the mortar may be considered as the cell-wall.*

* This illustration must be carried no further than to show the relation of *position* of these two parts of a cell.

3. Protoplasm.—The protoplasm is the essential part of the cell. It constructs the cell-wall. Rarely, if ever, is it uniform throughout, but is differentiated into distinct members, each having special work to do. In the most completely differentiated active cells the greater part of the protoplasm consists of a finely granular or nearly transparent, colorless portion, called *cytoplasm*. Embedded in the cytoplasm are the *nucleus*, *centrospheres* (figs. 1 and 2), and *plastids* (figs. 3 to 8).

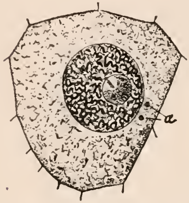


FIG. 1.—A cell (the megaspore) from a lily ovule, filled with granular protoplasm, in which is embedded a large spherical nucleus, containing a nucleolus, and accompanied by two centrospheres, *a*. The line around the protoplasm represents the cell-wall, with those of the adjacent cells connected. Magnified 500 diam.—After Guignard.

4. Cytoplasm.—This is not a single substance, but a mixture of several different substances, so intimately mixed and so unstable that it is not possible to analyze it. Moreover, the nature and amount of the components are probably variable. Most of the substances belong to the class of compounds called *proteids*, so that cytoplasm responds to proteid tests and is often spoken of as a mixture of proteids. In addition there are frequently present *other organic substances* (such as amides, carbohydrates, fats, and enzymes), and always small quantities of mineral matters which appear as *ash* when cytoplasm is completely burned. The minute granules embedded in the cytoplasm are of various nature. Most of them are solid substances.

5. Vacuoles.—Scarcely distinguishable from these at first are the minute cavities, called *vacuoles*, filled with dilute watery solutions of many different substances, the *cell-sap*. In all but the youngest cells more or fewer of these bubbles of water may unite to form larger ones (fig. 7). These often increase so as to occupy the greater part of the space within

the cell-wall, being separated only by plates of protoplasm. When all vacuoles fuse into one the cytoplasm is crowded as a thin layer against the wall, with sometimes strands of it crossing the vacuole as the remnants of the plates at an earlier stage (fig. 188).

6. Nucleus.—The nucleus varies much in shape. In cells whose diameters are nearly equal, it is generally spherical or ovoid, but in elongated cells it may become spindle-shaped or cylindric. It is surrounded by a very delicate membrane, and is composed of two sorts of substances, one of which can be readily stained by certain liquid dyes, while the other usually remains uncolored (fig. 2). The nucleus

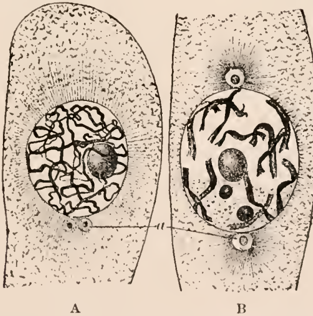


FIG. 2.—A part of the same cell as in fig. 1, but older, with the nucleus beginning to divide. The dark thread in *A*, separated into pieces in *B*, represents the chromatin of the nucleus deeply stained, the rest of the nuclear material being unstained. *a*, centrospheres. Magnified 600 diam.—After Guignard.

may divide into two, a regular succession of changes in the arrangement of the materials composing it characterizing this process, which is commonly followed by the formation of a partition-wall separating the cell into two parts, each containing one of the daughter-nuclei.

7. Centrospheres.—The centrospheres are intimately related to the nucleus. They are two very minute spherical bodies lying in contact with it (figs. 1, 2). When the nucleus is about to divide one centrosphere goes to each pole (fig. 2, *B*), and the separation of the nuclear material occurs near the nuclear equator. Just as this occurs the centrospheres divide, forming a pair at each pole. Two accompany each daughter-nucleus. Their purpose is not yet fully understood.

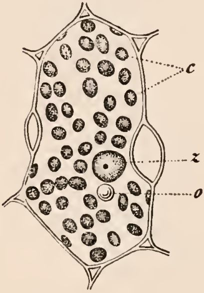


FIG. 3.

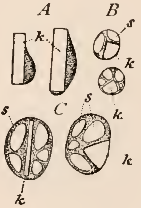


FIG. 4.

FIG. 5.

FIG. 3.—A cell from the interior of the leaf of the oat, showing its wall, and some inclusions of the cytoplasm. *z*, the nucleus; *c*, chloroplasts; *o*, an oil-drop. Magnified about 100 diam.—After Zimmermann.

FIG. 4.—*A*, chloroplasts from the skin of the petiole of ivy; *B*, from the inner leaf-cells of morning-glory; *C*, from the same cells of Achyranthes. The shaded parts are protoplasm in which are embedded starch-granules, *s*, and proteid crystalloids, *k*. Magnified about 1000 diam.—After Zimmermann.

FIG. 5.—Leucoplasts from a young shoot of Canna. The shaded part is protoplasm, in which are embedded starch-grains, *s*, and proteid crystalloids, *k*. Magnified about 1000 diam.—After Schimper.

8. Plastids.—In most cells there are also other protoplasmic structures, the *plastids*. In young cells these are small, rounded, colorless bodies. As the cell grows older they increase in size and number. At maturity, in cells which lie near the surface of green plants, they are commonly roundish or biscuit-shaped, of spongy texture, and colored yellowish-

green by a substance known as *chlorophyll.* These are consequently known as *chloroplasts* or chlorophyll-bodies (figs. 3, 4). In other cells, particularly those for the storage of food, they may develop into smaller, denser, flattened or roundish, uncolored bodies, called *leucoplasts* (figs. 5, 6, 7). These may act either as starch-accumulators, or in case

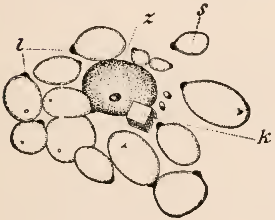


FIG. 6.

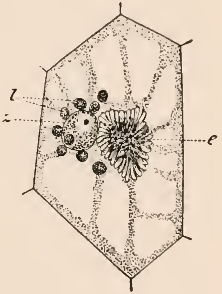


FIG. 7.

FIG. 6.—Part of the cell-contents of an inner cell of white potato. *z*, nucleus; *s*, starch-grains, each having been formed by a leucoplast, *l*, which is still attached to one side of the grain; *k*, crystalloid. Magnified abont 1000 diam.—After Zimmermann.

FIG. 7.—Leucoplasts in place in a young cell of a leaf of vanilla. *l*, leucoplasts; *z*, nucleus; *e*, an oil-former or elaioplast. The unshaded spaces surrounded by protoplasm are vacuoles. Magnified about 1000 diam.—After Wakker.

of need, in young cells, may even be converted into chloroplasts. In other cells, particularly in highly colored parts, the plastids may become of most diverse form and size, and colored red or yellow, whence they are called *chromoplasts* or color-bodies (figs. 8, 9).

9. **Wall.**—The cell-wall is formed by the protoplasm. In green plants when first formed it consists chiefly of *cellulose,* with which, as it grows older, various other substances may be mixed. Some of these, such as pectin, are present even in the young wall, and may increase with age; others

are characteristic of special changes which the wall may undergo. The most noticeable changes are four: (1) Some cell-walls contain *suberin* or *cutin*, fat-like substances by the presence of which water and gases are hindered from passing

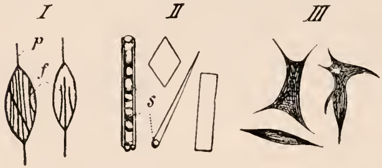


FIG. 8.

FIG. 9.

FIG. 8.—I, chromoplasts from flower-leaves of an orchid; II, from the root of carrot; III, from the fruit of mountain-ash. Embedded in the protoplasmic body of the chromoplast are sometimes proteid crystalloids, *p*, pigment-crystals, *f*, or starch-grains, *s*. Magnified about 1000 diam.—After Schimper.

FIG. 9.—Chromoplasts from the flesh-colored shoots of the horsetail, containing the coloring matter in the form of granules embedded in colorless protoplasm. Magnified 1400 diam.—After Zimmermann.

through. The cell-walls of bottle-cork are *suberized*, and those in the skin of the apple are *cutinized*. (2) Some cell-walls are *lignified*, as, for example, those of wood by reason of

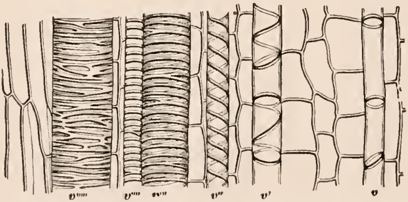


FIG. 10.—A part of a thin slice lengthwise through the centre of the stem of garden-balsam. The cells and vessels are elongated and are here seen from the side, showing the thickened lines on the side walls of v, v', v'', v''', v'''', and v'''''. Magnified about 400 diam.—After Duchartre.

the presence of certain substances (vanillin, coniferin, etc.). They allow the ready passage of water and gases. (3) Others are so transformed that, in contact with water, they swell enormously, forming a mucilage or gum. These swelling

substances are produced by the alteration of the cellulose or other constituents of the original wall. (4) An excessive deposit of mineral matters in the wall is known as *mineralization*. Such walls may even retain their form after all organic matter is burned out, as in the skin of the scouring rush or horsetail.

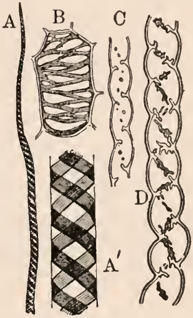


FIG 11.—Cells from a liverwort showing thickened walls *A*, half an elater; *A′*, a part more highly magnified; *B*, a cell from the lower part of the thallus, with reticulate thickenings (shaded); *C*, *D*, rhizoids with isolated branched thickenings. Highly magnified. — After Sachs.

10. Growth of the cell-wall.— As the cells become older the wall may increase in thickness. It must also increase in area as the cells grow in size. The growth in area is usually accomplished by putting new particles between the older ones. Growth in thickness is rarely uniform. When the wall grows thicker except at certain spots, these remain as pits or pores in the thickening layers. When only certain spots or lines grow thicker, the wall shows projecting spikes, bands, or threads, which give it the appearance in figs. 10, 11.

CHAPTER I.

SINGLE-CELLED PLANTS AND COLONIES.

In the lakes and pools, in ditches and slow streams, on the surface of damp rocks and wood, may be found many sorts of microscopic plants, whose entire body is merely a single cell.

Blue-green algæ.

11. Fission-algæ.—The simplest forms of these, the fission-algæ, have the protoplasm only slightly differentiated. The central part becomes the nucleus, while the whole of the remaining protoplasm is colored by the chlorophyll and a blue coloring matter called *phycocyanin*, so that in mass these algæ look bluish-green or even blackish. For this reason they are called blue-green algæ to distinguish them from those in which only the yellow-green of chlorophyll is present.

12. Gelatinous colonies.—The cell-wall may be a thin sheet of cellulose, but commonly it is composed of several layers, of which the outer are changed into mucilage. This swells into a transparent jelly when wet, either becoming homogeneous or showing distinct stratification. When a number of such forms grow in company (fig. 12), this jelly-like material blends into a single mass in which the protoplasm of the associated plants seems to be embedded.

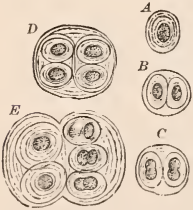


Fig. 12.—A blue-green alga (*Glœocapsa*). Single individuals, *A*, and colonies (*B–E*) of various ages Magnified 300 diam.—After Sachs.

13. Gelatinous filament-colonies.—In other cases, instead of being associated only by the adhesion of the mucilaginous portion of the cell-wall, the cells, still practically independent the one of the other, remain connected by the

firmer portions of the wall into rows, forming irregularly coiled or serpentine filaments, which are embedded in a profuse gelatinous material (fig. 13). The essential independence of the individual cells, even though they remain connected, is shown by the fact that such a chain may be

FIG. 13.—*Nostoc.* *A*, a gelatinous colony, irregularly lobed. Natural size. *B*, a portion of a serpentine filament with five heterocysts (one at each end by which it was separated from the rest of the cells composing the filament, and three intermediate ones) and the jelly belonging to it. Magnified about 400 diam.—After Thuret and Janczewski.

broken up into any number of pieces and each piece will retain all its powers. Here and there in the chain there occur cells unlike the rest (*h*, fig. 14), called *heterocysts*, whose function seems to be to break the chain into pieces, from the growth of which independent colonies may arise. The association of considerable numbers of these plants in colonies gives rise to masses of jelly which vary from the size of a pin-head to 2–5 centimeters in diameter. They may be found adhering to water-weeds as clear- or dirty-green masses, or sometimes floating free (*A*, fig. 13).

14. Filaments of loose organization.—Of very near kin to these plants are the oscillarias, which have received this name from the pendulum-like swinging of their tips (fig. 15). In them the cells remain connected more extensively and more firmly, so that each is disk-shaped, and the filament is much less easily separated into its component cells. More-

over the gelatinous part of the wall is much less prominent, so that often it is only seen with difficulty. Even though invisible, it may be detected by the slippery feel of the plants when rubbed gently between the fingers.

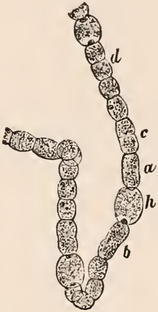


Fig. 14.

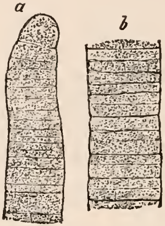


Fig. 15.

Fig. 14.—Part of a filament of *Anabæna*. *h*, heterocyst; *a–d*, successive stages in the division of a cell of the filament. Magnified 540 diam.—After Strasburger.
Fig. 15.—*Oscillaria*. *a*, the tip; *b*, a portion of the middle of a filament. Magnified 540 diam.—After Strasburger.

15. Feeding habits.—The feeding habits of the oscillarias are worth notice. They are found in permanent puddles and ditches *where organic matter is decaying*. The significance of this is that some of the ancestors of the green oscillarias probably had offspring which, instead of living upon food prepared by means of the green coloring matter (see ¶ 230), learned to utilize the organic matter in the water, at first perhaps no more than the present oscillarias do; but gradually they came to live exclusively upon it. As a consequence, they lost their color and became incapable of existing where organic food cannot be had.

Bacteria.

16. Fission-fungi.—Along with the loss of color and change of habit went a diminution in size. They have thus

become so different that they are now known as fission-fungi, and popularly as bacteria, bacilli, microbes, germs, etc. These plants, probably the descendants of common ancestors with the fission-algæ, are the smallest known organisms (figs. 16, 17). The diameter of many sorts does not

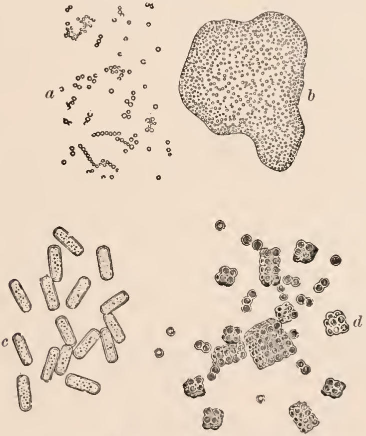


FIG. 16.—Various bacteria. *a*, *Micrococcus*, the "blood-portent"; *b*, zooglœa form of the same; *c*, *Bacterium aceti*, the ferment of vinegar; *d*, *Sarcina*, a harmless parasite of the human intestine. *a*, *b*, magnified 300 diam.; *c*, 2000 diam.; *d*, 800 diam.—After Kerner.

exceed .0005 of a millimeter. That would allow 175 to lie side by side upon the *edge* of the paper on which this book is printed. In many the successive divisions are parallel, in others they divide the cells in two planes, and in others again in three. The cells, when they divide, separate readily, in most sorts never cohering at all, but living as independent cells as soon as produced. Other sorts remain connected into two- to several-celled chains, sheet, or packets (*a*, *d*, fig. 16). A few have their cells firmly coherent into

a filament. As the cells are either spherical or rod-like, the shape of the colony depends upon the shape of the component cells and the way in which they divide (see ¶ 24).

17. Gelatin.—In the fission-fungi, as in the fission-algæ, considerable masses of gelatinous material are produced, in which the cells may lie embedded. The films, sometimes smooth, sometimes wrinkled, which appear on an infusion of organic matter, are formed by the masses of bacteria which become embedded in the gelatinous material produced by the alteration of their cell-walls (*b*, fig. 16).

18. Cilia.—Most species are furnished with locomotor organs consisting of fine threads of cytoplasm protruded through the wall, which, by their sudden contraction on one side, lash about like whips, and propel the cell by jerky, darting motions through the fluid in which it swims. These lashes, called *cilia*, may be single at the ends of the cell (*C*, fig. 17), or many at ends or sides (*A*, fig. 17), or the

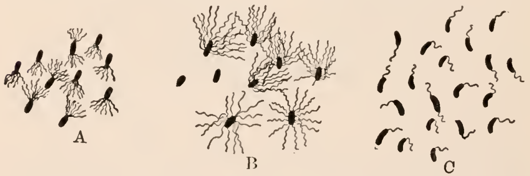


FIG. 17.—Bacteria stained to show cilia. *A*, cilia tufted at one end; *B*, cilia irregularly distributed over body; *C*, cilium single at one or both ends. *B*, the bacillus of typhoid fever; *C*, the bacillus of Asiatic cholera. Magnified 775 diam.—After Migula.

whole cell may be covered with them like hairs (*B*, fig. 17). They may be withdrawn or drop off when the plant comes to rest, as when they form the scums previously mentioned.

These plants are most interesting on account of their economic relation to health and disease, decay, fermentation, etc., which cannot be discussed here.*

* For further information on these plants, see *Frankland:* Our Secret Friends and Foes; *Prudden:* Story of the Bacteria, Dust and

Yellow-green algæ.

19. Single-celled plants with chloroplasts.—Among the single-celled green plants, one of the most common groups

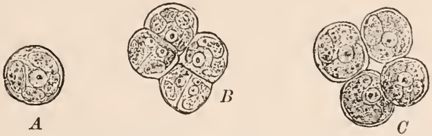


FIG. 18.—*Pleurococcus viridis.* *A*, a single individual; *B*, a colony shortly after division; *C*, the same after separation. Magnified 540 diam.—After Strasburger.

is that represented by fig. 18, which shows a representative of an extensive series in which the vegetative body consists of a single cell with its wall, cytoplasm, nucleus, and a few relatively large chloroplasts. In this greater specialization of the protoplasm, these plants show the only advance upon the blue-green algæ. The wall in such as this *Pleurococcus* is almost uniform and quite thin.

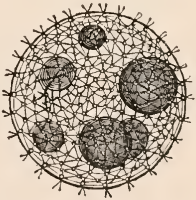


FIG. 19.—*Volvox*, a colony. The individuals are represented by the minute circles, between which the protoplasmic strands form a network. The large balls in the interior are daughter-colonies to be set free upon the rupture and death of the mother-colony. Magnified about 45 diam.—From Bessey.

20. Colonies.—The cells are frequently associated in colonies, embedded in jelly or not. The most striking and elaborate of these colonies is formed by *Volvox* (fig. 19).

In this plant the colony is a hollow sphere, often large enough to be seen by the naked eye as a minute green ball, composed of thousands of individuals, embedded in a common jelly, arranged in a single layer at the surface. Each is connected with its immediate neighbors by strands of protoplasm, and two

its Dangers, Drinking-water and Ice Supplies; *Russell:* Dairy Bacteriology; *Frankel* (tr. by *Linsley*): Bacteriology (medical).

cilia are protruded into the water outside. The lashing of these rolls the whole colony about. Each vegetative individual is entirely like the others, but those connected with reproduction become specialized.

Diatoms and desmids.

21. Shelled plants.—Other one-celled plants constitute a group known as diatoms, found in both fresh and salt waters,

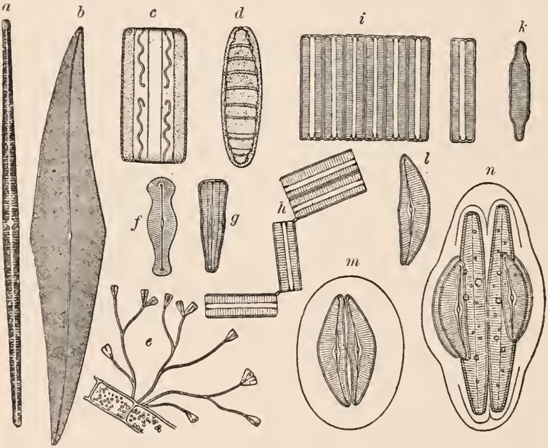


FIG. 20.—Various diatoms. *a*, *Synedra* ; *b*, *Pleurosigma* ; *c*, *d*, *Grammatophora*, side and top views ; *e*, colony of *Gomphonema*, with branched stalks attached to an alga ; *f*, *g*, single cells of same, more magnified, top and side views ; *h*, colony of *Diatoma*, the cells connected into a zigzag band ; *i*, *k*, colony and individuals (top and side views) of *Fragillaria* ; *l*, *m*, *n*, *Cocconema*. In *m* the pair is surrounded by jelly preliminary to the escape of the protoplasm and the formation of two new cells (auxospores) which has been completed in *n*.—After Kerner.

either attached or free-swimming (figs. 20, 21). The diatoms are very various in form, and present two different aspects. When seen from the side they are generally elongated-rectangular. When looked at from above they are short-cylindric, disk-shaped, boat-shaped, or variously curved

or angular. They are peculiar in having the cell-wall so impregnated with silica that scarcely any organic matter is left. Indeed the plants may be heated to a red heat and boiled in acid without destroying the form and markings of the cell-wall, so completely has it become silicified. To permit growth this rigid cell-wall is constructed in two pieces which fit together like the two parts of a pill-box (fig. 21). Each of these pieces, or valves, is sculptured into regular patterns in lines and dots, which are often so excessively minute or close together as to be barely visible with the highest powers of the microscope (*b*, fig. 20). Seen in mass, as they may often be on the sides of a glass aquarium, living diatoms appear yellowish-brown. The chloroplasts, which are sometimes single and always few, contain a brownish pigment (*diatomin*) in addition to the green chlorophyll.

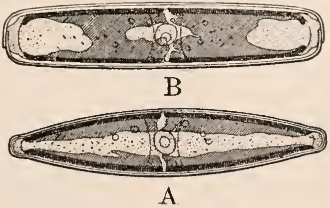


FIG. 21.—A single diatom (*Navicula amphirhynchus*). *A*, top view ; *B*, side view, showing overlapping of the valves. The parts shaded by lines are the chloroplasts; the dotted part the protoplasm, with nucleus about the center of cell. Magnified 750 diam.—After Pfitzer.

It is not uncommon for the diatoms to form colonies by the adhesion of several or many individuals by means of gelatinous cell-walls. These colonies are ribbon-like, or zigzag chains, or even branched filaments (*h*, *i*, fig. 20). Other sorts may be attached singly or in clusters by a gelatinous stalk (*e*, fig. 20). In all cases the jelly, like the rest of the cell-wall, is a product of the protoplasm. The slow

gliding movements of some free diatoms are due to the protrusion of strands of cytoplasm through slits in the valves.

22. The desmids.—These form another group of one-celled green algæ. They have neither the brownish color nor siliceous wall characteristic of diatoms, but are bright green cells of remarkably diverse and often beautiful forms. As a rule the cell is flattened and is divided almost into two by a deep constriction near the middle (*a, b, c, e*, fig. 22).

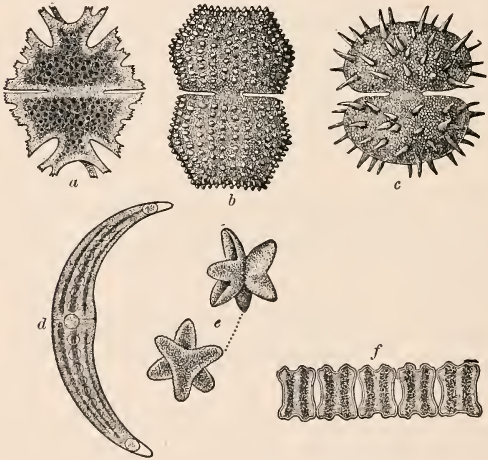


FIG. 22.—Various desmids. *a*, *Micrasterias*; *b*, *Cosmarium*; *c*, *Xanthidium*; *d*, *Closterium*; *e*, *Staurastrum*; *f*, *Aptogonum*. Magnified about 200 diam. —After Kerner.

Often the body of the cell is covered with warts or spine-like projections (*b, c*, fig. 22), or is prolonged into horn-like or hair-like lobes. These plants also frequently cohere into colonies (*f*, fig. 22). In that case tooth-like projections of the cell-wall may interlock.

CHAPTER II.

LINEAR AND SUPERFICIAL AGGREGATES.

OBVIOUSLY some of the plants mentioned in the last chapter, such as the oscillarias, are colonies of cells well on the way to complete union into coherent filaments whose elements are attached to each other by considerable areas of the cell-wall. In order clearly to understand this condition, we must consider the mode of origin of the individual cells composing the row.

23. Fission.—Under conditions unknown to us, in the course of its growth a cell may divide by a process known

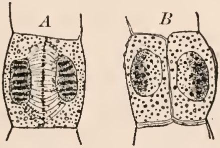


FIG. 22A.—*A*, one of the final stages in cell-division. The daughter-nuclei are still connected by kinoplasmic filaments, and across the equatorial plane particles of new cell-wall material are formed. *B*, the completion of cell-division; the daughter-nuclei have rounded off and the new wall is like the lateral walls. Magnified 880 diam.—After Strasburger.

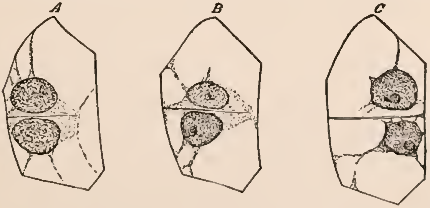


FIG 22B.—Three stages of division in the same cell of an orchid (*Epipactis palustris*). The cell is occupied in great part by vacuoles. In this case the new wall forms first on one side between the nuclei (*A*), which gradually travel across to the opposite side (*B*), the wall extending until it is complete (*C*). Magnified about 380 diam.—After Treub.

as fission. The material of the nucleus passes through a complex series of changes and separates into two parts. In a plane between these daughter-nuclei particles are deposited to form a cell-wall (*A*, fig. 22A). The formation of the partition-wall may occur simultaneously in all parts, or it may be formed on one side first and the nuclei move across the cell until it joins the lateral walls (fig. 22B). In this way an isolated unicellular plant of *Pleurococcus* (*A*, fig. 18) may divide into two cells so that it consists of two hemispherical cells, each capable of independent growth (fig. 23, *A*). After a time these cells may separate from each other by the cracking of the original wall at the line of juncture with the new partition and the cleaving of this partition parallel to its surfaces into two layers, one of which covers a portion of each of the thus disconnected cells (fig. 18, *C*). If this process of division and separation goes on, the result will be the production of a number of independent cells more or less closely associated but not connected.

24. Cell-rows, surfaces, and masses.—In many cases, however, a second division occurs in one or both cells before

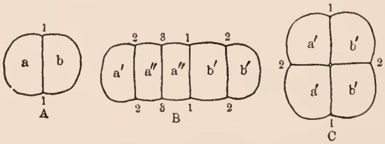


FIG. 23.—Diagrams of cell division. *A*, division of a spherical cell into two hemispherical cells, *a*, *b*, by the wall 1. *B*, the same after further division in planes 2, 2, 3, parallel to 1. *a* has divided by wall 2 into *a′* and another cell which has again divided by wall 3 into *a″*, *a″*. *b* has divided into *b′*, *b′*, the inner of which has elongated preparatory to a division into *b″*, *b″*, as by wall 3. *C*, fig. *A* after a second division, by wall 2, at right angles to 1.

separation; and sometimes even a third division takes place. It is evident that the position of the later partitions determines the form of this temporary aggregate of cells. (*a*) If each of the two divides in a plane parallel to the first parti-

tion, a *row* of four cells will result; the two inner cells would be disks or short cylinders, while the two outer would be hemispheres (fig. 23, *B*). (*b*) But if (as is actually the case in *Pleurococcus*, *B*, fig. 18) the new partitions are at right angles with the first, the result is a cluster of four cells, each of which is a quarter of a sphere (fig. 23, *C*).

Should a third division occur, it is conceivable that the new septa might be placed parallel to those already formed, in case *a*; or parallel to one set and at right angles with the other, in case *b*; or at right angles to both, in case *c*. In the first instance there would be formed a row, or filament, of eight cells; in the second, a sheet of eight cells; or, in the third, a mass of eight cells. This exhausts the possibilities in the position of successive partitions. If other divisions occur, they will necessarily be more or less nearly parallel to some one of the first three sets.*

The structures resulting from cell-division where the cells remain united are conveniently designated as follows: (1) *cell-rows*, filaments, or linear aggregates, arising by division in one plane; (2) *cell-surfaces*, or superficial aggregates, arising by division in two planes; (3) *cell-masses*, or solid aggregates, arising by division in three planes.

It is manifest that there are likely to be all degrees of union remaining between the cells of linear and superficial aggregates, and that the extent and firmness of such union will depend largely upon the character of the wall. As in every other case, the artificial distinction between cell-colonies and cell-aggregates is bridged by all manner of intermediate forms.

Filamentous algæ.

There is a large number of plants in which the vegetative body throughout life has the form of a filament. The green

* The formation of partitions at angles other than 90° or 180° to preceding ones would not affect the general result, but would only render the form of the product, as well as of the individual cells, less regular.

plants of this sort live almost entirely in water or in wet places, and may be conveniently designated as the *filamentous algæ*.

25. Spirogyra, etc.—Among these none are more beautiful or interesting than the filamentous Conjugatæ, represented in

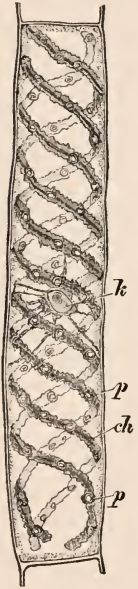


FIG. 24.

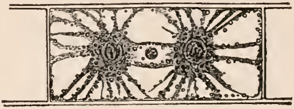


FIG. 25.

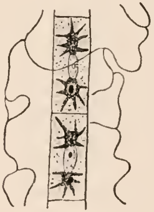


FIG. 26.

FIG. 24.—A cell from filament of *Spirogyra*. *ch*, chloroplast (there are three in this cell); *p*, pyrenoids; *k*, nucleus. Magnified 200 diam.—After Strasburger.

FIG. 25.—A cell from filament of *Zygnema*, showing two stellate chloroplasts, in each of which is a pyrenoid, with the nucleus between them. Cytoplasm poorly shown. Magnified 550 diam.—After Sachs.

FIG. 26.—Two cells from filament of *Zygnema*, showing the gelatinous sheath greatly swollen. Magnified 245 diam.—After Klebs.

our waters by the genera, *Spirogyra*, *Zygnema*, *Mesocarpus*, and some others.* They may be readily recognized, during their vegetative period, by their unbranched filaments, bright

*To the Conjugatæ also belong the single-celled desmids already described.

green color, and slippery "feel" between the fingers.* Under the microscope, they are at once distinguished from other filamentous algæ by the shape of their chloroplasts. In *Spirogyra* these form one or more flattish, spirally wound ribbons, notched on the edges, and embedded in the protoplasm near the cell-wall (*ch*, fig. 24). In *Zygnema* there are generally two irregularly star-shaped chloroplasts (figs. 25, 26); while in *Mesocarpus* a single flat, plate-like chloroplast, nearly as wide as the cell, traverses its center (fig. 27).†

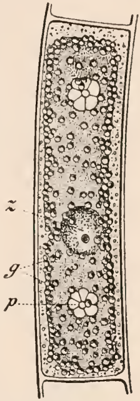


FIG. 27.—A cell from filament of *Mesocarpus*. The darker body nearly filling cell is the chloroplast (face view) in which are pyrenoids, *p*, and tannin vesicles, *g*. If seen from a direction at right angles it would appear as a narrow stripe in the center of the cell. *z*, the nucleus. Magnified about 200 diam.—After Zimmermann.

Embedded in the chloroplasts of these and other algæ are usually seen one or more angular, colorless bodies, often surrounded by a jacket of starch. These are crystals of reserve proteid, known as *pyrenoids* (*p*, figs. 24, 27). Their size depends upon the amount of reserve food possessed by the plant.

In these plants there is little or no difference between the parts of the filaments. If broken into two, each part may continue growing with no damage to any part except the cells which were ruptured in severing the plant.

26. Ulothrix, etc. — But other filamentous algæ show a distinction between base and apex. In *Ulothrix* (fig. 301)

* This slipperiness is due to the gelatinous outer part of the cell-wall (fig. 26), which is only visible after special treatment or on examining the filaments in a thin mechanical solution of Chinese ink.

† See also Ulothrix (fig. 301), which has in each cell a single chloroplast in the form of a thick ring.

the basal cell is elongated and pointed, and is colorless, because it is not furnished with chloroplasts like the others. By this pointed cell the plant is loosely attached, at least when young, to the substratum, while the green portion waves freely in the water. Thus arises a distinction into two parts, viz., the *rhizoid* and the *thallus.*

In *Cladophora*, *Vaucheria*, and their allies, the plants are generally attached by a well-developed rhizoid-region, which is often branched (*w*, fig. 28), as is also the thallus. In

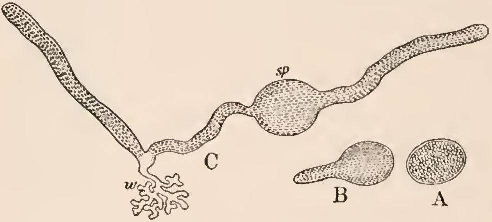


FIG. 28.—A young plant of *Vaucheria*, developing from the spore. *A*, mature spore ; *B*, the same after germination has begun ; *C*, plant further developed from spore, *sp*, with growing apex, *s*, and rhizoid, *w*, by which it attaches itself to the mud. The chloroplasts are numerous and close together next the wall on all sides. Magnified 28 diam.—After Sachs.

contrast with the preceding, therefore, *localization of growth*, producing branching, may be observed.

27. Branching.—A branch begins by the growth in area of a limited portion of the cell-wall. The pressure of the contained protoplasm upon the wall causes it to bulge outward at this point, and the convexity gradually increases as the region grows until the swelling becomes an outgrowth, whose further lengthening constitutes a branch similar to the main filament. Growth in length may be limited to the tip of the filament, or to a narrow zone including one or more cells, or it may occur indifferently in any part.

28. Cœnocytes.—Many algæ, while externally like others, which are divided into true cells, have not the units of

structure separated by cell-walls. In *Vaucheria*, for example, the whole of the vegetative body forms a single chamber, in which lies the united protoplasm, corresponding to many cells, as shown by the numerous nuclei which are distributed through it. The external walls of the cells are formed, but, when the nuclei divide as growth proceeds, the protoplasm does not divide, and the *septa* or partition-walls are not formed. Such an unseptate company of cells is called a *cœnocyte*.

In the cladophoras (fig. 29) some of the normal divisions are complete, while others are only nuclear divisions. Consequently the cladophoras seem to be a filament of true cells, but in reality each apparent cell is a cœnocyte, as shown by the several nuclei in each (fig. 30).

FIG. 29.—A single plant of *Cladophora*, showing profuse monopodial branching. Natural size. — After Hauck.

29. External segmentation. — A plant body of this construction may attain considerable size and complexity, as in *Caulerpa* (fig. 31) and *Acetabularia* (fig. 32),* even to mimicking, upon a small scale, the form of leafy plants. In such cases the external walls become considerably thickened, and across the protoplasm and its large vacuoles, from one side of the chamber to the other, run irregular bars of cellulose which act as braces to prevent the collapse of the outer walls (fig. 33).

In *Caulerpa*, particularly, a high degree of development as to external form is reached (fig. 31). There is a stem-like axis, *v–s*, creeping in the mud, which bears green leaf-like branches, *b*, on one side and clusters of colorless root-

* Note carefully the scale of the figures.

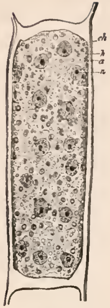


FIG. 30.

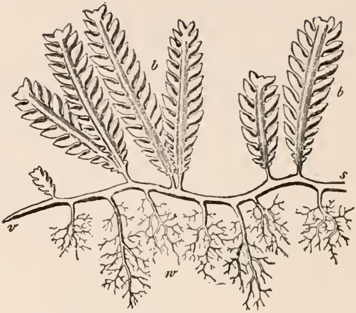


FIG. 31.

FIG. 30.—One cœnocyte from a branch of *Cladophora*, showing fifteen nuclei. *ch*, chloroplasts; *h*, pyrenoids; *a*, starch-grains; *n*, nuclei. Magnified 270 diam.—After Strasburger.

FIG. 31.—Part of a plant of *Caulerpa*. See text, ¶ 29. Two-thirds natural size.—After Sachs.

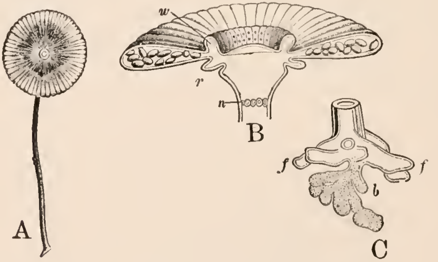


FIG. 32.—*Acetabularia*. *A*, an entire plant, natural size.—After Woronin. *B*, diagrammatic longitudinal section through the upper end of the stalk and the umbrella-like circle of crowded branches which grow together; *n*, scars left by fall of an earlier whorl of short branches; *r*, *w*, rudimentary branches; *C*, the base of stalk showing rhizoids for attachment, *f*, and for storage, *b*. Magnified 20 diam.—After De Bary and Strasburger.

like branches, *w*, on the other. Not only are a base (posterior end) and an apex (anterior end) distinguishable, but the plant shows a difference between an upper (dorsal) and under (ventral) side, the leaf-like thallus lobes arising from the dorsal side, while rhizoids spring from the ventral side.

FIG. 33. – Transverse section of axis of *Caulerpa*, showing cross-bars to stiffen wall. Magnified about 25 diam.— After Murray.

30. The thallus. — To the loose aggregation of single cells into colonies of definite form, as well as to the body formed by their more intimate union in the linear and superficial aggregates just described, the name *thallus* is applied. The term is most frequently applied to those more complicated forms which constitute the vegetative bodies of the higher algæ, which are now to be described.

CHAPTER III.

THE THALLUS OF THE HIGHER ALGÆ.

31. From linear to solid aggregates.—From the filamentous algæ, whose body is a linear aggregate of cells, it is but a step to those forms whose body is a *superficial* aggregate. When *Monostroma* grows from the single cell as which it begins life, the cell-divisions, instead of occurring successively in parallel planes, are made in two planes at right angles to each other. The result is a single sheet of cells forming a leaf-like thallus attached to stones or other algæ. The broader forms are sometimes 20–25 cm. wide.

Ulva, a near relative, develops in much the same way, but at least one series of divisions occurs in a third plane, at right angles to the other two, so that the body of the sea-lettuce consists of two layers of cells. As fig. 34 shows, it is very clearly differentiated into rhizoid and thallus.

FIG. 34.—A small plant of *Ulva lactuca*, the sea lettuce, showing thallus, and rhizoid for attaching it to rocks. Natural size.—From Bessey.

If two such layers separate from each other, as they do in *Enteromorpha*, a hollow, sac-like body is formed.

So, from the linear aggregates, we pass through *superficial* to *solid* aggregates of a broadly extended form.

The transition from linear to solid aggregates of slender

form may be understood by comparing with one of the filamentous algæ a member of an isolated order of green fresh-water algæ, the *Characeæ*.

Characeæ.

32. The order.—These plants constitute an outlying group of considerable antiquity, having no near relatives living, yet showing in the vegetative body some structural resemblance to the filamentous algæ, while, as a whole, their external form imitates quite closely that of the higher plants (figs. 35, 36). The species of *Chara* and *Nitella* (the two genera which make up the bulk of this order) are found in almost every temperate region, growing in dense masses submerged and rooting in the mud in quiet waters. They reach a height of 10–75 cm.

33. External form.—The plants agree in having a central axis, at certain points of which* arise lateral outgrowths of two kinds. One kind forms a circle of branches, nearly like the main axis, except that their growth is limited. These themselves bear branches of simpler structure. The primary whorled branches are the so-called "leaves," and the secondary ones which these bear are the so-called "leaflets."

Just above one of the "leaves" in each whorl is produced a branch precisely like the main axis, which has, like it, unlimited growth.

34. The main axis.—In Nitella the axis consists of alternately long and short cells, a very short cell occurring at each point ("node") where branching occurs. The long cell extends from one "node" to another. This "internodal"

* Commonly called *nodes*, and the intervals *internodes*. These terms, imposed from analogies with the seed-plants, are entirely misleading from a morphological point of view, as are also the names "leaves" and "leaflets," applied to certain divisions of the axis, but they have become so fixed that it is difficult to avoid their use.

FIG. 35.—Upper part of a plant of *Chara*, showing whorled branches of limited growth ("leaves"), and at three lower "nodes" branches of unlimited growth, the lowest being cut off. The small bodies on the "leaves" are "leaflets" and sex-organs. Natural size.—After Wille.

cell is, therefore, of an extraordinary length, as well as of large diameter.

FIG. 36.—Upper part of a plant of *Nitella*. Natural size.—After Wille.

35. Cortex.—Nitella and Chara are much alike, except that in Chara the main axis and all its branches are composed of a row of large cells, surrounded by a jacket of smaller ones (fig. 37). The walls of these outer cells are often much thickened, and incrusted with salts of lime to such an extent as to render the axis very brittle. Around the main axis the cell-jacket is of much complexity; it becomes more simple

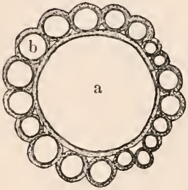


FIG. 37.

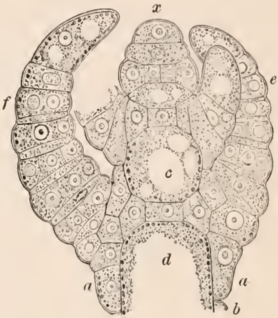


FIG. 38.

FIG. 37.—Transverse section of the axis of *Chara*. *a*, internodal cell; *b*, cortical cells Magnified about 30 diam.—From a drawing by C. E. Allen.

FIG. 38.—Longitudinal section of apex of axis of *Chara*. *x*, apical cell. The segment next below will divide into a nodal and an internodal cell; the next one has already divided and the nodal half has again divided into two internal and several external (only 2 show) nodal cells. *c*, *d*, internodal cells; between them a node producing the branches ("leaves") *e* and *f*, and the cortical branches *a*, *a*. *b*, a similar branch growing up from node below, only its tip showing. Magnified 330 diam.—After Sachs.

upon the whorled branches, and is wanting upon the ultimate divisions.

While a cross-section of the axis shows a complete union between the walls of the cortical cells (*b*, fig. 37) and the central one (*a*, fig. 37), a study of their development shows that they are originally branches of the outer cells at each node, which likewise produce the circle of "leaves." The

branches from the node above grow downward and others from the node below grow upward until they meet and interlock about the middle of the internode (fig. 38). Thus, the cortical cells are not produced by division from the large central cell which they cover and stiffen, but simply grow over it and become united with it at a very early age, increasing with its growth and undergoing division at the same time, so that each cortical branch becomes multicellular.

36. Apical cell.—The axis and all its branches, in both genera, are produced by the growth of a single apical cell of hemispherical form (x, fig. 38). The segments, successively cut off by partition-walls from its base, each divide a second time. One of the cells so produced increases rapidly in size, and becomes the internodal cell, while the other, by successive divisions and differentiation, forms the node and its appendages. In those branches which show unlimited growth the apical cell retains its hemispherical form until death; but in the divisions with limited growth ("leaves") it becomes pointed and ceases to cut off segments from the base.

37. Rhizoids.—The structures by which the Characeæ are held in place are adapted to penetrate the soft mud of the ponds and lakes in which they grow. From the nodes near the base of the axis arise numerous colorless rhizoids, often of considerable strength through thickening of the cell-walls.

The thallus shows decided increase in specialization of members. This is accomplished, however, with a minimum of differentiation in the cells of which the body is composed.

Polysiphonia.

In the marine algæ a still higher specialization of members is reached. One of the red seaweeds may be used to show the gradual advance in complexity.

38. External form.—The body of *Polysiphonia*, a branching alga (fig. 39) which grows in abundance upon rocky

seacoasts, is not divided into nodes and internodes, and the branches are differently arranged from those of Chara. The axis is made up in its larger parts of five or more rows of cells, the central or axial row being surrounded by a jacket of at least four others (fig. 40). But these originate by division from the central one, and are not, as in Chara, merely adherent to it. It is, however, only in the larger parts of the axis that

FIG. 39.

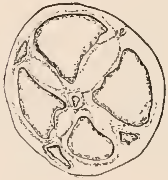


FIG. 40.

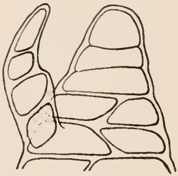


FIG. 41.

FIG. 39.—An entire plant of *Polysiphonia*, showing mode of branching. Natural size.—After Kützing. (See fig. 229.)
FIG. 40.—Transverse section of one of the branches of *Polysiphonia*, showing a minute central cell with four large and four small cells surrounding it. Magnified about 50 diam.—From a drawing by Mr. Grant Smith.
FIG. 41.—Apex of a branch of *Polysiphonia* which has nearly ceased growing. Magnified about 100 diam.—From a drawing by Miss Rowan.

this structure appears; at the tips even of the main axis the body is a linear aggregate (fig. 41). Polysiphonia, therefore, may be looked upon as one of the simplest forms of a *solid aggregate.*

39. Apical cell.—As in Chara, growth in length is quite definitely localized, because it is the elongated terminal cell of either the main or secondary axes (fig. 41) which produces, by division near its base, the new cells whose subsequent enlargement and division give rise to the axis. In some red algæ the chambers are not cells but cœnocytes, as shown by the several nuclei.

40. Color.—In this plant, as in very many of the marine

algæ, there exists, in addition to the green of the chloroplasts, a special coloring matter, called *phycoerythrin*. To the naked eye, this color overpowers the green and gives the

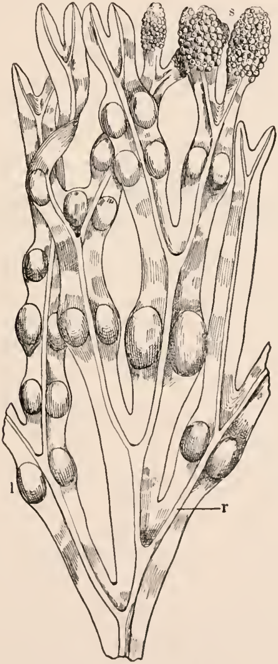


FIG. 42.—Upper part of a plant of *Fucus vesiculosus*. *r*, midrib of thallus; *l*, bladders; *s*, swollen tips covered by numerous elevations, in each of which is a pit (conceptacle) which contains many sex-organs. Two thirds natural size.—After Luerssen.

plant a pink tinge. In other red algæ it is often present in greater quantity and variety of hue, so that brilliant reds and

purples, with shadings of brown and green, mark the more striking species.

Fucus.

From the very simple body of *Polysiphonia* to the common bladder-wrack, or *Fucus vesiculosus*, there are all stages of complexity, which cannot be traced here.

41. External form.—The body of Fucus (fig. 42), is large as compared with the plants previously described. It is often 75–100 cm. long by 1–2 cm. broad, of greenish-

Fig. 43.—A transverse section of the thallus of *Fucus*, showing midrib, *r*; cortex, *c*; medulla, *m*; and a hair-pit, *p*. Magnified 10 diam.—From a drawing by Mr. C. E. Allen.

brown color and cartilaginous consistency. Near the base the thallus is contracted into a stalk whose extremity is broadened into a sucker-like disk (often lobed) which attaches the plant firmly to the wave-washed rocks on which it grows. Above, the thallus is flattened, with a thicker rib in the middle (fig. 43), and branches abundantly by forking. These branches, though often twisted, really lie in the same place as the flattening. Here and there the axis shows pairs of oval swellings, the bladders, which, by the contained gases, give greater buoyancy to the plants in the water.

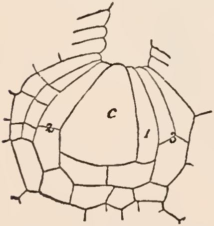


Fig. 44.—A longitudinal section through the apical meristem of *Fucus*, at right angles to the flattened sides of body. *c*, apical cell; 3, 2, 1, segments successively cut off from *c* by its division; 3, being the oldest, has already become divided into three cells. Magnified 200 diam. —After Rostafinski.

42. Apical cell.—An examination of the structure of the thallus shows a decided differentiation of cells, which would be expected from the large and complex

form. At the apex of any growing branch is found a cluster of angular cells, thin-walled, of nearly uniform size, with abundant protoplasmic contents, and all in close contact. One of these cells, lying in the center of the group, somewhat larger and of different shape from the rest (*c*, fig. 44), is constantly undergoing division, and thus cutting off cells (segments) from its two inner faces (1, 2, 3, fig. 44). The cells so produced undergo further divisions, forming thereby all the cells of which the thallus is composed. This group of dividing cells is present in all the higher plants. It constitutes the "growing point" or, better, the *apical* (or primary) *meristem*. The single cell from which all proceed in Fucus is called the *initial*, or *apical*, *cell*.

43. Differentiation of cells.—But if a thin section of the thallus, from an older part, be examined (fig. 45), its cells will be found very different from those at the apex. The cells nearer the surface are smaller and of different form from those in the interior. They are also close-set, whereas those in the interior are no longer in contact with each other on all sides, but have been separated by the growing of branches from the cortical cells between them. These filamentous branches are crossed and interlaced, with wide *intercellular* spaces. All of these older cells have enlarged, and, instead of being filled with protoplasm, they will be found to have large vacuoles and heterogeneous contents.

FIG. 45.—Diagram of a portion of fig. 44, magnified about 70 diam. *c* cortex; *m*, medulla. The varied forms of the cells are due to the different planes in which the filaments are cut. The clear spaces are filled with mucilage produced by the cell-walls. From a drawing by Mr. C. E. Allen.

The walls, also, are no longer thin and homogeneous, but have become thickened and differentiated into at least two layers, the outer of which is capable of swelling enormously in water, while the inner layer retains its usual form. There

arises thus a *cortex*, as the outer dense part is called, and a *medulla* or pith, as the mucilaginous and apparently isolated central cells and filaments are called. At the bladders, the pith becomes filled with air and other gases.

44. Special functions.—Complete examination of all parts, the disk of attachment, the bladders, and the hair-pits (fig.

FIG. 46.—Several plants of *Lessonia*, showing tree-like thallus and branched rhizoids attaching the plants to rocks. $\frac{1}{30}$ natural size.—After Le Maout & Decaisne.

43) with which many species are covered, would reveal still other modes of differentiation of cells from those of the apical meristem. Accompanying the change of form is always specialization of function, which we can interpret only in a very imperfect fashion from our own standpoint.

The compact small cells forming the surface are nutritive and probably in part protective; the bladders serve to increase the buoyancy of the plants when the tide is in; while the abundant mucilage, formed in the interior from the cell-walls, serves to retain the moisture when the plants are ex-

FIG. 47.—A plant of *Sargassum*, showing differentiation of thallus. Natural size.—After Bennett & Murray.

posed by the ebbing tide; the hair-pits are functionless, so far as known; and the strong, elastic cells of the disk and stalk above hold the plants in place as they sway constantly back and forth in every wave of the rising or falling tide.

45. Color.—The coloring matter in the chloroplasts of Fucus and other brown seaweeds is chlorophyll (green) and

phycophæin (brown). The chloroplasts exist chiefly in the cortex, which is, therefore, the food-making tissue (see ¶ 230), while the internal tissues are used for storage of reserve food.

46. Intercalary zones of growth.—Some of the brown seaweeds, instead of growing at the tip, grow in a zone at the base of the flatter part of the thallus, just above the round stalk. Such growth is called *intercalary* growth. There can be no single initial cell, but at least a zone of initials.

Some species grow to great lengths. One Australian species is said to attain a length of 200–300 meters. Still others have the form of a tree, the stalk-like portion representing the trunk, with a crown of flattened, frond-like branches above (fig. 46).

The thallus in the "gulf-weed," or "sea-grape" * (fig. 47), is still further differentiated into rounded, stem-like parts and flattened, leaf-like ones. The bladders are berry-like enlargements in the middle of short, rounded branches, and the form is strikingly like that of a small herb.

* This plant is of interest, also, because from its scientific name, *Sargassum*, is derived the name of that region in the North Atlantic, in the loop of the Gulf Stream, the Sargasso Sea, where the plants accumulate after being torn off the tropical shores on which various species grow.

CHAPTER IV.

THE FUNGUS BODY OF HYPHAL ELEMENTS.

Fungi.

FUNGI are plants without chlorophyll, whose body is generally made up of long filaments, either loosely or densely interwoven and united.

47. Origin.—As the bacteria, the smallest and simplest plants, were derived from the lowest algæ by slow adaptation to a different kind of food, so, at various points in the ascending scale of algal life, certain algæ have adapted themselves to the use of organic food which they could secure ready-made. These, having no use for the chlorophyll and chloroplasts, have gradually lost them. The adoption of the habit has proved highly successful, both among the simple bacteria and the more highly organized true fungi. The ancestors of the present species were—how long ago no one can say—probably at first chiefly, if not exclusively, aquatic. Some, at the present time, have the same habit, growing in infusions of organic matter. Others attach themselves to dead or even living animals or plants in the water. The soil (containing in its upper layers more or less organic matter from the offal of plants and animals, or from their dead bodies) and dead or living organisms furnish places of growth for a great number of species which have adapted themselves to other than aquatic life.

48. Hyphæ.—The filaments of which the fungus body is

composed are called hyphæ. Each is the result of growth from a single cell, and is comparable to the thread-like body of the filamentous algæ.

There is, naturally, a great variety in the hyphæ of different species of fungi. Some are relatively large; others very small; some of even diameter and caliber, others irregular and with unequally thickened walls; some very thin-walled, others very thick-walled. Between these extremes is to be found a complete gradation.

They grow in length at the apex only. In many kinds partitions are formed at more or less regular intervals, as the growth in length proceeds. In others no partition-walls are formed, though division of the nucleus takes place. Even when transverse partitions are formed, they do not separate the filaments into cells, but each chamber, or sometimes the whole filament, is a cœnocyte.

49. Branching.—As the hyphæ elongate, branching may occur. If a branch is to be formed, a limited area of the cell-wall begins to grow more rapidly than the rest. This allows a slight bulging of the growing region; the swelling increases and soon takes the form of a branch, like the main axis. It may remain short or continue to grow indefinitely in length. Commonly a septum is formed at the base of the branch. If such a branch arises first as a minute pimple, so that it remains connected with the parent axis by a small neck, and has only limited growth in length, it is called a bud and the process is known as *budding* (fig. 48). Such branches are usually easily broken off, thus readily producing independent plants. (See further under Reproduction, ¶ 302.) In some species of

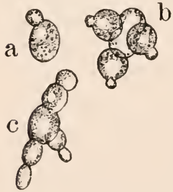


FIG. 48.—Beer-yeast (*Saccharomyces cerevisiæ*). *a*, a full-grown plant with a branch (bud) partially developed. *b*, *c*, colonies formed by budding, the individuals still attached. Magnified 750 diam.—After Reess.

fungi, profuse branching is the rule; in others, the branches are few.

50. Mycelium.—When branching is profuse, or when a considerable number of individuals grow near together, the filaments often become interwoven and entangled in so com-

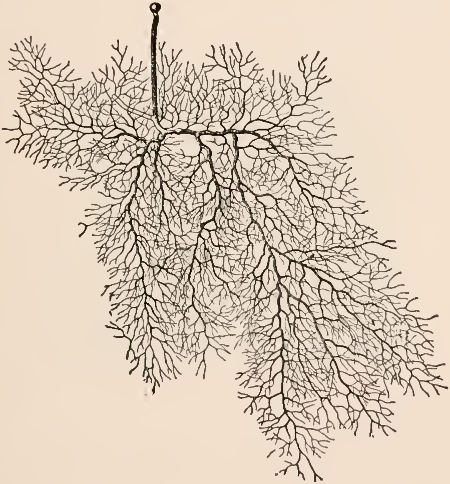


Fig. 49.—A single plant of *Mucor Mucedo*, showing the mycelium as it developed from a single spore in an infusion of dung. It bears a single erect reproductive branch rising above the fluid. Magnified 25 diam.—After Brefeld.

plex a web that it is impossible to follow a single hypha for any distance. Such a mat of hyphæ is called a mycelium, a term which is also used to designate the vegetative hyphæ collectively, whether forming a felted mass or not (figs. 49, 50). The mycelium may be formed wholly upon the sur-

face of the object upon which the fungus lives; or parts of it may be superficial, and part may penetrate that object; or all of it may be hidden within the substratum.* In some of the common molds (Mucorini), the cobwebby threads lying upon the surface of the substratum constitute the exposed part of the mycelium, while other hyphæ penetrate deeper;

FIG. 50.—A section of part of the aerial body of *Polyporus*. *sp*, hyphæ running at an angle to the section, cut across; *K*, crystals of oxalate of lime. Magnified about 500 diam. After Vogl.

in others (Penicillium, etc.), the superficial hyphæ become so interwoven that they may be lifted off the substratum (as from jellies, jams, syrups, etc.) as a coherent layer. But in most cases, especially when the fungus grows on a solid medium, the hyphæ become adherent to it and permeate it so that they cannot be separated from it, even by the most careful dissection.

* This non-committal term may be used to designate the material upon which the vegetative part of the fungus grows, whether it be a living body, a dead organism, or organic matter in solid or liquid form.

51. Parasites.—Especially is this true of those fungi which grow in the interior of living organisms. The higher plants are liable to be fastened upon by parasitic fungi, and compelled to act as *hosts* to their unbidden and unwelcome guests. Such a host plant may be entered when a mere seedling, in which case the fungus grows with its growth, or it may not be attacked until older or even mature. The host may be permeated in all its parts by the fungus filaments; or certain members, only, such as the leaves, flower parts or twigs,

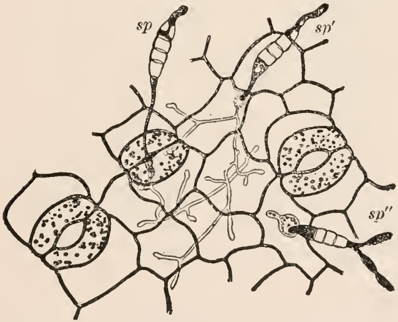


FIG. 51.—Young hyphæ of *Exobasidium* developing from spores, *sp*, entering the air-pores of the leaf of the cranberry. Others, from *sp′*, *sp″*, penetrate the skin directly. Magnified about 600 diam.—After Woronin.

may be affected. The effect of the fungus upon the host is often scarcely visible to the unaided eye; sometimes a local disturbance is manifested by swelling, unnatural color or growth;* sometimes the affected members become distorted and useless or are even killed; sometimes the disease is general and is followed, slowly or quickly, by general death of the host.

52. Infection.—These internal parasites obtain entrance

* See further ¶¶ 222, 464.

to their hosts in various ways. Sometimes the young hypha, growing from a special reproductive body (spore),* so minute that it may easily float in the air and fall upon a leaf, creeps along the surface till it finds one of the microscopic openings in the skin of the leaf, into which it grows (*sp*, fig. 51). These external openings are connected with irregular spaces between most of the cells of the softer parts, which are also the parts in which the food-supply is most abundant. In these, therefore, the fungus develops, breaking out to the surface again to form or set free its reproductive bodies.

FIG. 52.—Hyphæ of *Trametes Pini* perforating the walls of a wood-cell (at *c*) of Scotch pine and destroying the primary wall of the cell. *d*, *e*, holes made by hyphæ. Magnified about 800 diam. —After R. Hartig.

Or, the young hyphæ may excrete at their tips a substance which so softens or dissolves the cell-walls of the host that they penetrate these cells readily, not only at the surface (*sp'*, *sp''*, fig. 51), but in the interior.† They then branch freely, often growing in the spaces between the cells, often passing through the cells themselves (fig. 52).

Plants are often attacked when mere seedlings. Either from a bit of mycelium or a spore which has survived the winter or the dry season, a hypha grows, which, almost as soon as the seedling emerges from the seed, penetrates it. The fungus, in these cases, may develop quickly and kill the

* See ¶ 304 and the following.

† It is not improbable that the penetration of cell-walls is assisted by such pressure as the growing hypha can exert, but the relative action of enzymes and pressure has not been determined.

young plant (as in the "damping off" disease in greenhouses), or it may develop slowly and not reach maturity until the host is mature.

53. Haustoria.—Those fungi which grow upon the surfaces of living plants (and those which grow in the internal air-spaces) often have special branches for fastening themselves to the host or absorbing food from it. In the surface

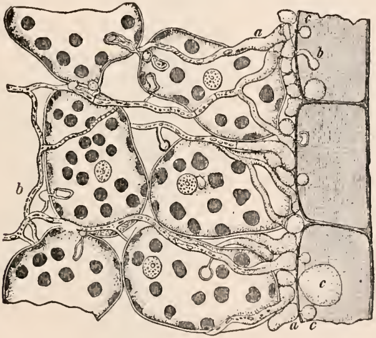


FIG. 53.—Epidermis and a few cortical cells of cowberry with mycelium of *Calyptospora* occupying the intercellular spaces and pressing knob-like ends against the cells from which a slender branch penetrates the wall and enlarges in the interior into sac-like haustoria, *b*, *b*. *a*, club-shaped hyphæ which produce spore-mother-cells, *c*, in the epidermis. Magnified 420 diam.—After R. Hartig.

fungi these are usually very short, disk-like or lobed branches which do not penetrate the cells of the host. In other cases they are branches of minute diameter, which enter the cells, and either enlarge into a knob (fig. 53) or branch profusely (fig. 54).

54. Fusion.—When the hyphæ of a fungus grow very close together, they frequently cohere and become so changed in appearance as to lose all trace of resemblance to filaments. Not only fusion but thickening and division

occur, and a section of the resulting structure has much the appearance of a section of the tissues of a higher plant (fig. 55). These changes are particularly apt to occur among the superficial parts of the more massive structures among the fungi, where they are necessary to impart firmness, rigidity, or durability. For example: in the ergot, a fungus common upon certain grasses, a portion of the mycelium is to survive the winter and grow again the next season. This portion

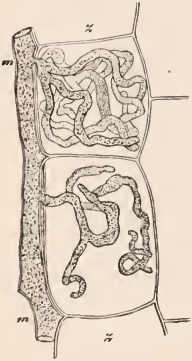


FIG. 54.

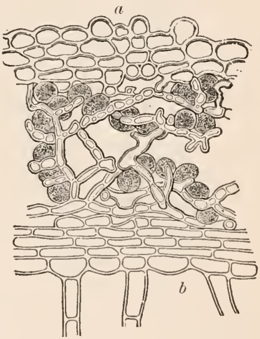


FIG. 5·.

FIG. 54.—Branching haustoria of *Peronospora*. *m*, *m*, the hypha traversing an intercellular space of the host; *z*, *z*, two haustoria penetrating two cells of the host and branching therein. The other contents of host-cells not shown. Magnified about 400 diam.—After De Bary.

FIG. 55.—A section through the mycelium of a lichen showing hyphæ near upper surface, *a*, and lower surface, *b*, fused into a false tissue; only in central region are the filaments recognizable. The dark spheres are imprisoned algæ. Magnified 650 diam. —After Bornet.

replaces the young ovulary of the flower (see ¶ 335), and, as it matures, becomes a dark-colored mass, as firm and resistant as the grain itself (fig. 56).

The interweaving and fusion of the hyphæ sometimes produce cord-like or strap-like structures of considerable size. The mycelia of the higher fungi frequently form them, and

they may be found in the leaf-mold of forests or in rotten stumps or between boards in wet places.

FIG. 56.—*a*, compact mycelium of ergot in the form of a grain-like body, replacing grain of rye ; *b*, the same germinating to form reproductive bodies. Natural size.—After Tulasne.

54a. Lichens.—The body of lichens is a mycelium woven about isolated unicellular algæ, colonies, or filaments,

which are thus imprisoned.* The fungus hyphæ usually predominate and in great measure determine the form of the body and its texture. Sometimes the algæ are present in such numbers that the hyphæ seem merely distributed among them. In form the body may be broad and thin (fig. 225), or slender and shrub-like. In texture it may be tough and leathery, with the hyphæ near the surface fused into a false tissue (*a*, *b*, fig. 55). When gelatinous algæ, such as Nostoc (see ¶ 13) are imprisoned, the body may be gelatinous. In all cases the algæ supply the fungus with food, and are in turn supplied with water absorbed by the spongy mycelium. (See further ¶¶ 195, 223, 462.)

* Rarely about other small green plants.

CHAPTER V.

LIVERWORTS AND MOSSES.

55. Alternation of generations.—In the liverworts and mosses, as in all the plants higher in the scale, there occur two well-marked phases in the course of their lives. One of these phases is marked by the formation of sexual reproductive cells, or *gametes* (see ¶ 369), the egg and sperm, whence it is called the sexual phase, or the *gametophyte*. The other is characterized by the formation of non-sexual reproductive cells, the *spores* (see ¶ 304), whence it is called the non-sexual phase, or *sporophyte*. These two phases alternate with each other, the sexual reproductive cells of the gametophyte producing, under suitable conditions, the sporophyte, whose non-sexual reproductive cells give rise to the gametophyte. To this regular sequence of the two phases the phrase *alternation of generations* has been applied.*

In the higher liverworts and mosses both phases have nutritive work to do, but in many this is confined to the gametophyte, and in all the gametophyte carries on the greater part of it. To this phase, therefore, attention is first given.

Liverworts.

56. The thallus.—The form and structure of the vegetative body of the simplest liverworts is scarcely different from

* Rather obscure suggestions of the alternation of generations are to be found among the algæ and fungi, but they are not definite enough to warrant discussion in this book. Let the student notice, however, that this feature does not appear suddenly in plant life, though introduced abruptly into the account of it.

that of some of the green algæ. The body is a thallus with rhizoids (fig. 57). The rhizoids are usually linear aggregates

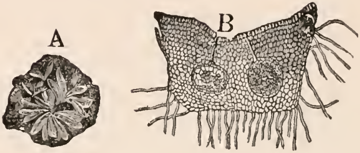


FIG. 57.—*A*, plants of *Riccia sorocarpa*, on the ground. Gametophyte phase. Natural size. *B*, a vertical section of one of the thick lobes of the thallus, showing nearly uniform structure. The thallus has nearly covered over two young sporophytes which appear as though in the interior. Rhizoids arise from the ventral side and flanks. Magnified about 25 diam.—After Bischoff.

of cells having thin walls and little protoplasm, arising from the under side and flanks of the thallus. They serve to

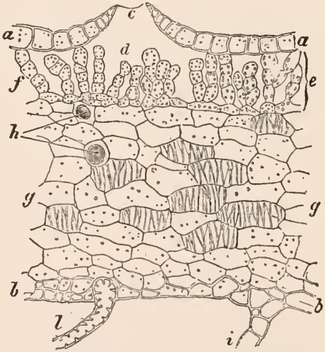


FIG 58.—Portion of a vertical section of the thallus of *Lunularia cruciata*. *a*, dorsal, *b*, ventral epidermis; *c*, an air-pore; *e*, air-chamber, from whose floor rise cell-filaments, *d*; *f*, partition between adjoining air-chambers; *g*, colorless cells containing starch, some showing net-like thickenings of the walls, others with oil-bodies, *h*; *i*, a ventral scale; *l*, a rhizoid. Magnified 110 diam.—After Nestler.

fasten the thallus to the substratum,—an adaptation to the terrestrial mode of life. The thallus is usually flat and

expanded in a horizontal plane, though sometimes much crisped. The simpler ones consist of several layers of uniform cells* (*B*, fig. 57).

57. The dorsiventral thallus.—In other forms there is a more decided difference between the upper and under sides of the thallus. The upper cells contain chloroplasts, while the under ones have none or very few. In the Marchantia family there are large air-chambers in the upper part of the thallus, from the floor of which arise filaments or cactus-like rows of chlorophyll-bearing cells (fig. 58). On the under side, also, are frequently found scale-like outgrowths (superficial aggregates), as in fig. 58, *i*.

A part which shows constant differences between an upper (dorsal) and an under (ventral) side is said to be *dorsiventral*, and the state of being thus different is termed *dorsiventrality*.

FIG. 59.—*Lunularia cruciata*, showing horizontal thallus and rhizoids with two erect branches (one young, one mature), for carrying sex-organs. Natural size.—After Bischoff.

58. Branching.—The branching of the thallus is always by forking, in a single plane or direction, as in Fucus, but the branches do not always develop equally. Sometimes special branches, instead of remaining horizontal, grow upright and develop into peculiar forms adapted to producing the sexual reproductive organs (fig. 59).

59. The growing point of the thallus is usually in a notch at the apex (fig. 60). There is a single apical cell of wedge shape (rarely tetrahedral), from whose inner faces segments are cut off (fig. 61). These, by division and growth,

* Cœnocytes rarely appear in the vegetative bodies of this or any higher group.

produce the whole thallus. The center of the thallus is generally thicker than the wings, and forms a sort of central rib (*B*, fig. 60).

60. The shoot.—In the greater number of liverworts the mature vegetative body is a shoot, which is differentiated

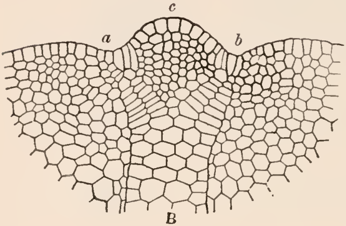


FIG. 60.

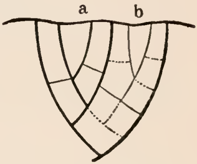


FIG. 61.

FIG. 60.—Surface view of growing apex of thallus of *Metzgeria furcata* just after forking. *a*, primary apical cell; *b*, secondary apical cell of branch; *c*, the wing-tissue between axis and branch outgrowing the apices. *B*, the midrib. Magnified 160 diam.—After Kny.

FIG. 61.—Diagram showing origin of branch in *Metzgeria furcata*. *a*, primary apical cell from which the segments right and left bounded by heavy lines have been cut off. All have undergone further division. In the right-hand one the latest cell-walls have been so placed as to form a wedge-shaped cell, *b*, which becomes the apical cell of a branch. Its early formation gives the (false) appearance of dichotomy.—After Kny.

into stem and leaves (figs. 62, 63). Even in such a body the dorsiventral character is well marked. The stem is a filiform axis of uniform cells, bearing three (rarely more or fewer) rows of leaves, of which the two dorsal rows are the larger, while the under leaves are much smaller, even to being inconspicuous or wanting. These leaves are superficial aggregates, consisting of uniform cells richly supplied with chloroplasts, as are also the outer cells of the stem. Their form is very varied and often of great beauty. They are always sessile and are usually crowded so closely as to overlap each other more or less, and hide the axis completely (fig. 63).

61. The origin of the leaves will be apparent upon comparing figures 64, 65, and 66. In Blasia (fig. 64) the thallus is lobed, i.e., the edge has not grown equally, but continued growing longer at certain points. In Fossombronia (fig. 65) the flattened thalloid form is still evident, but the lobing has become so deep

Fig. 62.

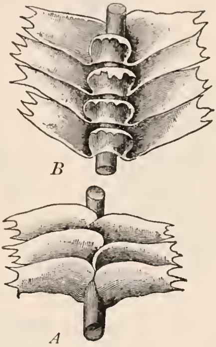


Fig. 63.

Fig. 62.—Gametophyte of *Bazzania Novæ-Hollandiæ*. Besides the ordinary branches there are slender ones (flagella) with sparse minute leaves. Natural size. —After Lindenberg and Gottsche.

Fig. 63.—*A*, dorsal view; *B*, ventral view of a piece of fig. 62, magnified about 12 diam., showing the stem, bearing two dorsal rows of large leaves and one ventral row of small ones.—After Lindenberg and Gottsche.

that the almost separate parts are usually called leaves. In Noteroclada (fig. 66) the central axis is still more compact, and has lost its flat form, becoming a rounded stem from whose flanks arise regular outgrowths, the leaves, each of which corresponds to one of the lobes of the thallus in the other forms.

Mosses.

In the mosses the complexity of the mature vegetative body is somewhat greater. It is always developed as a shoot differentiated into stem and leaves.

62. Rhizoids.—The shoot is anchored, as in the liver-

FIG. 64.

FIG. 65.

FIG. 64.—Part of a plant of *Blasia pusilla*. The flattened lobed thallus is the gametophyte; the stalked capsules (one young, one bursted) are two sporophytes attached to it. Magnified 4 diam.—After Schiffner.

FIG. 65.—Gametophyte and sporophyte of *Fossombronia cristata*. The thallus is so deeply lobed that the divisions are usually called leaves. Magnified 15 diam.—After Schiffner.

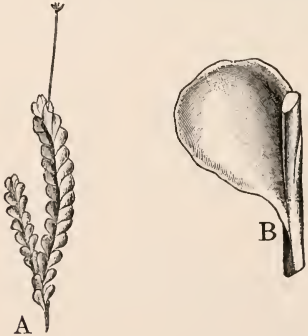


FIG. 66.—*A*, a gametophyte of *Noteroclada*, with a sporophyte attached. Natural size. *B*, a part of the stem and a single leaf of the same, magnified about 10 diam.—After Hooker.

worts, by numerous usually much branched rhizoids (*A*, fig. 67; *w*, fig. 68). Similar filaments may be produced, often in great numbers, along the stem and especially in the axils of the leaves, or they may even arise from the leaves themselves, when the plants grow in dense patches or in a very moist place.

FIG. 67.—*A*, gametophyte of *Polytrichum commune*, with rhizoids below. *B*, gametophyte of *Hylocomium splendens*, bearing three sporophytes near top. Natural size.—After Kerner.

63. The stem is usually cylindrical and covered by the crowded leaves. In structure it generally shows an advance upon that of the liverworts in having the whole of the outer region occupied by a distinct mass of mechanical tissue composed of thick-walled cells, and, near the center, a strand of elongated small cells, known as "conducting tissue" (fig. 68), though it is doubtful whether it conducts anything.

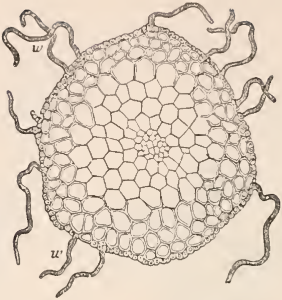


Fig. 68.—Transverse section of the stem of *Bryum roseum*. In the center the small cells make a central strand, the "conducting tissue"; the surface cells form an epidermis; the next three rows within also have thick walls and strengthen the stem; *w*, rhizoids arising from epidermis. Magnified 50 diam.—After Sachs.

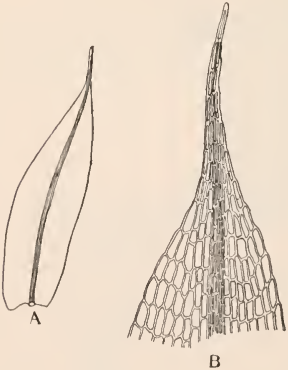


Fig. 69.

Fig. 70.

Fig. 69.—*A*, leaf of a moss (*Funaria Americana*), showing central rib. Magnified about 40 diam.; *B*, upper portion of the same leaf, highly magnified, showing single layer of cells forming the blade and the narrower cells of the thick rib.—After Sullivant.

Fig. 70.—Tip of leaf of a moss (*Oligotrichum aligerum*), showing the thickened rib, and the plate-like ridges on blade and rib greatly increasing the surface of nutritive tissue. Magnified about 75 diam.—After Sullivant.

64. The leaves are also more highly developed than in liverworts. They are always sessile and are arranged in two (rarely), three, or more vertical ranks along the stem, and consist usually of a single sheet of chlorophyll-bearing cells, the *blade* (figs. 69, 70), and a central rib running from base to apex (frequently wanting), which is composed of elongated conducting and strengthening cells (figs. 69, 70). In some the amount of green tissue is increased by the formation of vertical plates similar to the blade (fig. 70).

65. Branching.—The stem branches, often very profusely, by the formation of lateral growing points beneath the developing leaves. Sometimes the growth of the lateral branches, as of the original main axis, is checked by the formation of sexual organs. In that case a new branch is likely to arise some distance below the apex, so that the stem is a succession of lateral branches, called a *sympodium* (fig. 71). This mode of branching is termed *sympodial*. In other cases the main axis continues its growth unchecked, and more or fewer branches also develop. These lie plainly upon the sides of a central axis. This mode of branching is called *monopodial*. Often the growth of the lateral axes is definitely limited and their development regular, forming a pinnate branch-system. If the secondary axes themselves branch, there is formed a bipinnate or even tripinnate system, as in figure 67, *B*.

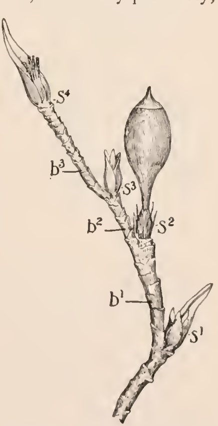


FIG. 71.—Axis of a moss (*Orthotrichum*) showing sympodial branching. S^1, S^2, S^3, S^4, successive clusters of sexual organs, produced at apex which check the growth of axis. Beneath each a lateral growing point develops, producing successively the brances b^1, b^2, b^3. Magnified 10 diam.—After Bruch & Schimper.

66. Protonema.—In its early stages the vegetative body of the *leafy* liverworts and the mosses is either a flat thallus, similar to the mature form of the thallose liverworts, or a branching filamentous body, called the *protonema*, almost identical with the form of the filamentous algæ. Upon this protonema the leafy shoot arises as a lateral bud, which soon outstrips it in growth and differentiates leaves. The protonema may live for some months, but generally perishes after having produced a few leafy plants.

67. Sporophyte.—The non-sexual phase in the liverworts and mosses has almost no vegetative functions, and a fuller

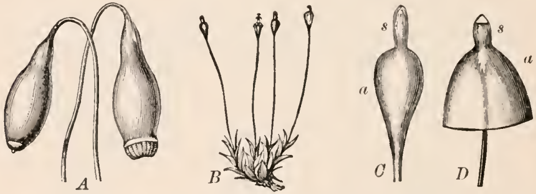


FIG. 72.—*A*, two capsules of Bryum; from the right-hand one the lid has fallen, showing the teeth. Magnified 5 diam. *B*, four gametophyte shoots of *Splachnum ampullaceum*, bearing four sporophytes. Natural size. *C*, a capsule of one of the same sporophytes, showing enlarged apophysis, *a*, below the sporangium, *s*. Magnified 10 diam. *D*, capsule of *Splachnum luteum*, with umbrella-like apophysis, *a*, below sporangium, *s*. Magnified 2 diam.

study of its structure is left for Part III. It consists at maturity of a yellowish or brown spherical or cylindrical case (fig. 72), which is sessile or raised upon a short or long stalk and contains (a few or) hundreds or thousands of reproductive cells called spores. The base of this stalk constitutes an organ called the "foot," which is embedded in the gametophyte (*f*, fig. 73).

68. Nutrition.—The surface of the young sporophyte, when large and well developed, as it is in the higher liverworts and mosses, is green. To a limited extent, therefore, it is able to make food; but not sufficient for its needs,

for these are great on account of its rapid growth and the supply required as reserve for each spore. The foot, being in close contact with the tissue of the gametophyte, acts as an absorbing organ, receiving food solutions from it. The sporophyte thus lives, in part at least, as a parasite upon the gametophyte.

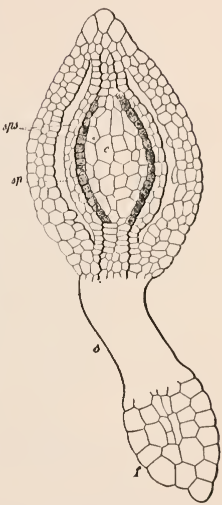


Fig. 73.—Young sporophyte of *Phascum cuspidatum.* *c*, columella; *f*, foot, embedded in gametophyte stem; *s*, seta (cells not shown); *sps*, sporangium; *sp*, spore-mother-cells. Magnified 80 diam.—After Kienitz-Gerloff.

In some mosses there is a tendency to increase the nutritive work of the sporophyte by developing at the top of the stalk, below the spore-case, a mass of green tissue. In Bryum (*A*, fig. 72) this gives the capsule a pear-shape, while in Splachnum (*B*, *C*, *D*, fig. 72) it is so far developed as to exceed the sporangium. In some species it is expanded into a miniature umbrella which, one can imagine, might readily become segmented into leaves.

The intimate attachment of sporophyte to gametophyte continues throughout the life of the former. Sometimes the gametophyte perishes at the close of the growing season, but more commonly it is perennial, growing and branching at the anterior end as the older posterior parts die away.

CHAPTER VI.

FERNWORTS AND SEED-PLANTS.

Fernworts.

AMONG the still more complex plants, the ferns and their allies, the same "alternation of generations" can be seen. The two "generations," or phases, have, however, changed much in relative size. Whereas in the liverworts and mosses the gametophyte is much the larger and more conspicuous, as well as the longer-lived, among fernworts the sexual phase is so much smaller that it is seldom seen; and in some species it is almost microscopic. On the other hand, the sporophyte is the phase which is usually seen and the only part popularly known.

69. The gametophyte.—The vegetative body of this phase of the fernworts in its best developed forms is a small, flattened, green body of oblong, orbicular, or cordate outline, commonly less than half a centimeter in diameter, rarely as much as 2 cm. (fig. 74). It is strikingly like a thallose liverwort in general form, being distinctly dorsiventral and having rhizoids on its under side, which fasten it in place. (Because of this thalloid form and because it seemed to precede the "real plant"—a popular phrase meaning the sporophyte—it was called a *prothallium*.) Only the central part of the gametophyte consists of more than one layer of cells. On the under side of this central

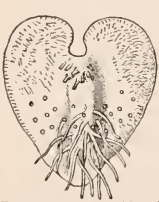


FIG. 74.—Ventral side of the gametophyte of a fern, *Asplenium*. The notched end is the anterior. Rhizoids near posterior end. The small circles show position of male organs; the chimney-like projections near anterior end the female organs. Magnified 10 diam.—After Kerner.

"cushion," as it is called, are produced the sexual organs. (See further under Reproduction, Part III.)

70. Reduction of gametophyte.—In a few of the fernworts the gametophyte is filamentous, or tuberous, and more or less

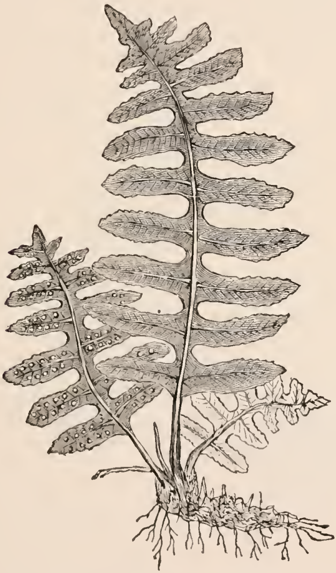


FIG. 75.—Sporophyte of a fern, *Polypodium vulgare*, showing horizontal underground stem, bearing secondary roots and leaves. Natural size.—From Bessey.

completely subterranean and colorless. Such prothallia derive their food from decaying plant-offal.

In higher plants of this group the gametophyte becomes still further reduced in size and structurally simplified, until in some species it is hardly more than a few cells surrounding the sexual organs. These reduced forms grow by the use of

food stored in the spore from which they originate. The gametophyte of such species has lost wholly its vegetative character, and is restricted in function to the production of the sexual organs.

71. The sporophyte.—In contrast with the smallness and simplicity of the gametophyte is the relatively large size and

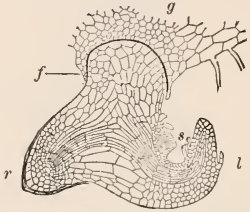


FIG. 76.—Embryo of *Pteris aquilina*, and a small part of the gametophyte, *g*, in which its foot, *f*, is embedded. *r*, the primary root; *s*, primary stem; *l*, primary leaf. Induced growth of the gametophyte about the foot is shown by small size and number of cells. Much magnified.—After Hofmeister.

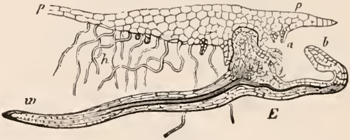


FIG. 77.—Section through embryo and gametophyte of maidenhair fern (*Adiantum Capillus-Veneris*). The embryo is older than that in fig. 76. *p*, *p*, gametophyte; *h*, rhizoids, among which are two spermaries. The eggs in three ovaries failed to develop; the other formed the embryo, *E*. *a*, primary stem, only slightly developed (compare *s*, fig. 76); *b*, primary leaf; *w*, primary root. The part embedded in the gametophyte is the foot. Magnified about 10 diam. After Sachs.

complexity of the sporophyte (fig. 75). It is always differentiated into stem and leaves, and, with rare exceptions, roots also. This great advance in the development of the sporophyte of the fernworts, as contrasted with its form in their nearest of kin below, the liverworts and mosses, suggests that the fernworts are a very old group; a hint which is confirmed by the antiquity of their fossil remains. It is also noteworthy that, as compared with mossworts, the chief work

of nutrition has been shifted from the gametophyte to the sporophyte; and this even when the gametophyte has its largest size and greatest duration, while nutritive work is wholly abandoned in the smaller forms. The sporophyte has also become the long-lived stage, the gametophyte being usually transitory (only exceptionally living more than one season), while the sporophyte lives through one season in the few annuals, and commonly for several or even many years.

72. The embryo.—The fertilized egg, from which the sporophyte arises, develops while still embedded in the gametophyte in which it is formed. Consequently the embryo sporophyte is, as in the mossworts, at first surrounded by the gametophyte (figs. 76, 77). The part of the gametophyte adjacent to the embryo grows under the stimulus of its presence, but the growth of the embryo is more rapid, and it consequently spreads apart the gametophyte (see figs. 76, 77). A portion of the embryo develops a temporary organ, the foot, which remains embedded in the gametophyte until the first root, stem, and leaf have been formed (fig. 78). Soon thereafter the gametophyte perishes and the foot, no longer useful, disappears.

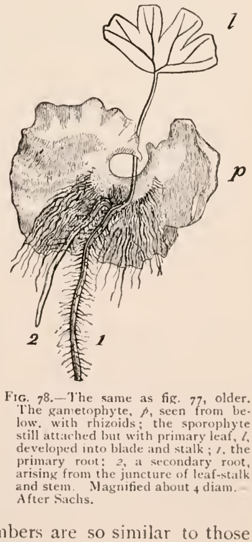


FIG. 78.—The same as fig. 77, older. The gametophyte, *p*, seen from below, with rhizoids; the sporophyte still attached but with primary leaf, *l*, developed into blade and stalk; *1*, the primary root; *2*, a secondary root, arising from the juncture of leaf-stalk and stem. Magnified about 4 diam. After Sachs.

73. Members.—The mature sporophyte is differentiated into root, stem, and leaves. The important adaptations of the structure and forms of these members are so similar to those

of the seed-plants that thay will be discussed in connection with them.

Seed-plants.

Among the highest plants, those which produce seeds, the differentiation of the body is essentially the same. The alternation of sexual and non-sexual phases is still traceable, though greatly obscured by the extreme reduction of the gametophyte. This tendency to the reduction of the sexual phase, which was remarked in passing from the mossworts to the fernworts, continues, until in the highest seed-plants the gametophyte is wholly microscopic. Even by the aid of the microscope, it is possible to identify only the sexual organs which it produces, and one or more cells which are, perhaps, the rudiments of its vegetative body. The sporophyte, consequently, is the only phase of the seed-plant visible to the unaided eye. The relation of the gametophyte to it will be explained in Part III.

The body of the sporophyte exhibits the same members, viz., stem, root, and leaf, having the same general form, and subject to the same modifications, as in the fernworts. To a discussion of the vegetative members of the fernworts and seed-plants we now turn.

CHAPTER VII.

THE ROOT.

74. Analogous members.—It has been pointed out that, among the lower plants, there are very many which possess structures similar in form and function to the root, and sometimes called by the same name. Although these parts serve to hold the plant in place, and perhaps to absorb material from the substratum, they are not to be looked upon as homologous with the roots of the higher plants, but as merely analogous with them. In the plants whose vegetative body is a thallus the gametophyte is the prominent phase. In no case does the gametophyte produce true roots. It is not until the sporophyte becomes an independent plant that true roots are found in the vegetable kingdom. It is, therefore, only among fernworts and seed-plants that these organs are to be found. When the sporophyte is developed as an independent plant, it becomes necessary for it to produce some organ capable of holding it in place, or of absorbing materials from the outside, or of doing both. The organ developed to meet this need is the root.

75. Primary roots.—In accordance with their origin, roots are either primary or secondary. Primary roots are those which are developed directly from the egg from which the entire plant takes its rise. The spherical egg in most of the fernworts begins its development by a division into hemispheres. The hemispheres divide into quadrants; each of the quadrant cells divides into two, forming octants of the original egg. Division continues and the fundaments of primary root, foot, stem, and one or more leaves appear

(see fig. 76). In many of the seed-plants the egg divides several times in parallel planes, forming a short filament, the *suspensor* (figs. 79–82). The terminal cell of this row may then give rise to an embryo, as just described, or this terminal cell and an adjacent one may take part in forming the embryo. In this case the terminal cell, by its divisions, either produces the primary leaf or leaves, or it produces the primary stem and leaves; while the second cell gives rise to the primary stem and root, or to the primary root alone (see figs. 80–82).

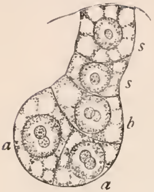


Fig. 79.—A very young embryo of the onion. *s*, *s*, cells of the suspensor; *a*, *a*, *b*, cells from which the embryo develops. Highly magnified.—After Sachs.

The two primary members formed from the root hemisphere of fernworts are not always permanent. The foot is

Fig. 80.

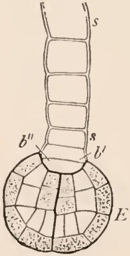


Fig. 81.

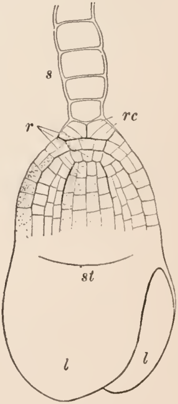


Fig. 82.

Fig. 80.—A very young embryo of shepherd's-purse. Suspensor, *s*, *s*, just completed, and first four cells of embryo formed by division of terminal one; the second cell, *b*, is to produce part of the root. Highly magnified.—After Hanstein

Fig. 81.—An older stage of the same. *E*, embryo; *b′*, *b″*, two cells resulting from division of *b*, fig. 80; *s*. *s*. suspensor. The shaded cells produce the skin and the vascular bundles Highly magnified.—After Hanstein.

Fig. 82.—An older embryo of same. *E*, embryo; *l*. *l*, primary leaves; *st*, apex of stem; *r*, primary root; *rc*, first layer of root-cap; *s*, suspensor. Cells shown only in part. Less magnified than preceding.—After Hanstein.

always temporary, disappearing as the embryo becomes larger. It is sometimes wanting from the first. In both fernworts and seed-plants the primary root is rarely wanting, but often short-lived, dying after the plant has established itself and has formed secondary roots to take its place. In many cases, however, the primary root persists throughout the life of the plant.

76. Secondary roots.—Secondary roots, on the contrary, are those which arise upon stem or leaf, or even upon the primary root itself. In the last case they are distinguished from branches of the primary root, which arise in regular succession toward the apex, by originating out of this regular order. Secondary roots are also called *adventitious* roots. They may take their origin at any point upon any of the members. Their point of origin will depend largely upon external conditions. They are especially likely to be formed upon those parts which are in contact with the substratum, or from those parts which are kept moist. Upon stems they are most apt to appear near the nodes. (See ¶ 119.) If the plant as a whole is surrounded by very moist air, roots may appear at any point of the surface. Secondary roots arising thus upon a part of the plant exposed to the air, and growing for all or part of their existence in the air, are also called *aerial* roots. Familiar examples are to be seen about the lower part of the stem of Indian corn, the English ivy, the poison-oak, the trunks of palms and tree-ferns. Secondary roots often arise in regular succession toward the growing apex of the stem, particularly in plants which have creeping or subterranean stems.

77. Growing point.—Primary and secondary roots do not differ materially in their structure. The early divisions of the quadrant cell which produces the primary root in fernworts are so arranged that a cell shaped like a four-sided pyramid is produced. This cell becomes the apical, or

initial, cell. It is situated with one face directed toward the apex of the root (see fig. 83), and the other three faces within it. Parallel to the three inner faces partitions are constantly formed in regular succession dividing this apical cell into two unequal portions, so that the smaller is looked upon as a segment cut off from the larger portion. If these inner faces be numbered respectively 1, 2, 3, the segments are constantly produced in the order of the numbers. These segments themselves divide to form other cells, and thus give rise to all the tissues of the root. This mass of actively dividing cells is the primary meristem or growing point of the root (compare ¶ 101). As the older cells of the primary meristem enlarge, divide, and differentiate, they are constantly pushing the apical cell further away from the older part. Not only are segments cut from the three inner faces of the apical cell, but, at less frequent intervals, partitions parallel to the outer face form similar segments. The division of these segments gives rise to a structure covering the very tip of the root, and connected with it for a short distance only. It receives, therefore, the appropriate name of *root-cap* (*ep*, fig. 83). Since the cells of the surface of the root-cap are older and firmer than the inner segments and the initial cell, and lie in front of them, they serve to protect the more delicate

FIG. 83.—Median longitudinal section through the extremity of a root of Marsilia. The large triangular cell near center of figure is the apical cell. The segments from the inner faces may be readily traced backward; thus the dotted line *ec* points to the fourth, *c* to the sixth segment from the posterior right-hand face of apical cell. *ep*, root-cap (epidermis); *ec*, cortex; *c*, stele; *en*, endodermis (part of cortex); *pe*, pericycle (part of stele). Magnified about 100 diam. —After Van Tieghem.

cells as the growth of those behind constantly pushes the apex forward through the soil.

In seed-plants, the segments of the egg which produce the

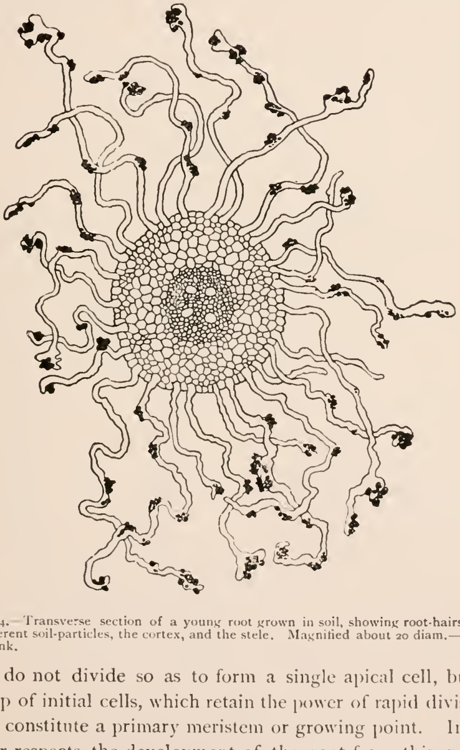


FIG. 84.—Transverse section of a young root grown in soil, showing root-hairs with adherent soil-particles, the cortex, and the stele. Magnified about 20 diam.—After Frank.

root do not divide so as to form a single apical cell, but a group of initial cells, which retain the power of rapid division and constitute a primary meristem or growing point. In all other respects the development of the root from this group of initials is similar to that already described.

In both cases, the differentiation of cells produced at the growing point results in the formation of three characteristic parts of the root, namely, (1) an outer layer or layers, the *epidermis ;* (2) an inner region, the *stele ;* (3) between these, the *cortex*.

78. 1. **The epidermis** usually becomes many-layered. At the apex it constitutes the *root-cap* (*ep*, fig. 83). On the other parts of the root it sometimes sloughs off entirely, exposing the cells of the cortex itself, as in the monocotyledons (lilies, grasses, sedges, etc.); or, more commonly, only the outer layer sloughs off, leaving the innermost as the covering of the cortex.

79. (*a*) **Root-hairs.**—Those cells which form the surface of the root, whether they be the original epidermis or cortical ones which have been exposed by its loss, usually develop a large number of hairs, known as *root-hairs* (fig. 84). These root-hairs are branches of the superficial cells (fig. 85), and may be looked upon as simple extensions of them, as the finger of a glove is the extension of its palm. Only one root-hair arises from a superficial cell. They are usually unbranched and without transverse partitions. Only in rare cases are they wanting. They live for a shorter or longer time, but are always, as compared with the duration of the root, quite transient. The older part of the

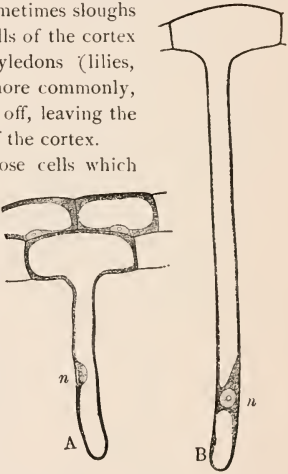


FIG. 85.—Two root-hairs showing structure and relation to superficial cells of root; grown in water and therefore not distorted as in fig. 84. *A*, the younger; *B*, older, nearly mature. *n*, nucleus embedded in cytoplasm; vacuole single and very large. Highly magnified.—After Frank.

root, therefore, is without root-hairs because of their death. The youngest part of the root is likewise free from them, because they have not yet been produced. As the root grows in length, new root-hairs are continually being produced and the older ones are dying at an equal rate, so that a zone of hairs is found only upon the younger parts of the roots.

80. (*b*) **The root-cap**, serving to protect the tenderer portion of the root behind, is itself constantly exposed to injury. The outer and older cells of the root-cap are, therefore, either torn away through mechanical contact, having become gradually loosened from each other with age; or, losing their active contents, they degenerate and break down into a slightly mucilaginous material which facilitates the passage of the root through the substratum. This degeneration or the mechanical wear is repaired constantly by the formation of new cells in the growing point. The thickness of the root-cap, therefore, is maintained throughout its existence without considerable change. It rarely becomes more than a few cell-layers thick. Since its tissue is produced only by the division of the apical cell or cells, it is organically connected with the root only at the very tip; but it usually extends backward over the root, by reason of its growth, for a considerable distance. If the finger be supposed to represent the root, a short finger-stall, if it were attached to the tip of the finger, might be fairly taken to represent the position of the root-cap. Only in rare cases is the root-cap entirely wanting.

81. 2. **The stele.**—Occupying the center of the root, and surrounded on all sides by the cortex, is an aggregate of tissues called the *central cylinder*, or *stele* (figs. 84, 86, 89). The outermost layer of its cells is the *pericycle* (figs. 86, 88, 89). Within this are found strands of elongated cells or cell-fusions,* called *vascular bundles*, or *strands*. These

* These are continuous chambers formed by the breaking down of the partition-walls between the abutting ends of cells. They are usually devoid of living contents.

bundles are of two kinds, *xylem* bundles and *phloem* bundles, so placed that they alternate with each other about the periphery of the stele (figs. 86, 88, 89). The xylem bundles may be in contact with one another in the center, or the center of the stele may be occupied by a pith (figs. 86, 89).

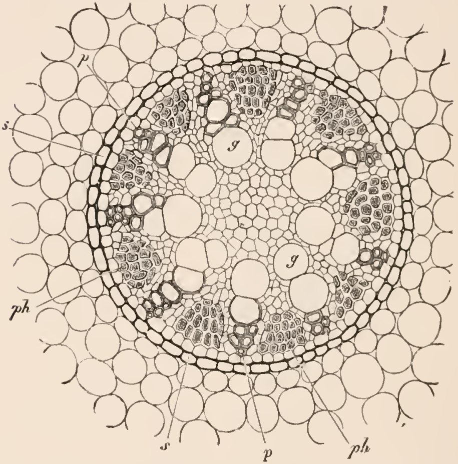


FIG. 86.—Transverse section of the stele and a portion of the surrounding cortex of the root of calamus. *s*, *s*, innermost layer of cortex, the endodermis, adjoining outermost layer of stele, the pericycle; *p*, xylem bundles; *ph*, phloem bundles. The shaded elements of xylem bundles are the primary xylem; the large ones, *g*, are secondary. In the center of the stele and between the bundles is conjunctive tissue. Highly magnified. —After Sachs.

The tissues of the xylem are usually lignified (see ¶ 9) and, when abundant, make up what is called the *wood*. They are the chief water-conducting elements of the older parts of the root.

The tissues of the phloem are usually not lignified, and the most important ones are the *sieve-tubes*, which conduct proteids from above to the growing regions of the root.

The number of vascular strands constituting the stele is various, being as few as four or as many as forty. The ordinary number, however, is from eight to twenty. (See figs. 86, 89.)

82. 3. **The cortex** generally consists of large thin-walled cells which have become partially separated from each other, leaving larger or smaller intercellular spaces (figs. 86, 89). Its innermost layer, bordering the stele, is usually quite different from the rest, and is recognizable by its wavy, radial walls, which are suberized (¶ 9). This layer is called the endodermis (figs. 86, 88, 89).

83. Duration. — Even when the primary root persists throughout the entire life of the plant secondary roots often appear. When the primary root perishes, its functions must be performed wholly by secondary roots, which are developed in succession upon those parts where they are useful. The secondary roots themselves may be either permanent or transient. In creeping plants particularly, whether growing on land or in water, the functions of the root are likely to be handed on to successively younger roots, the old ones perishing and dropping off. If the roots endure for a considerable time, they may retain their primitive structure and form, or they may undergo *secondary changes* which unfit them for absorbing organs, and adapt them to subserve various special functions.

84. Secondary changes.—Shortly after any portion of the root has ceased to increase in length, and, therefore, within the first season, it ordinarily undergoes minor secondary changes which may or may not be followed by more profound alterations. These changes affect its primary structure in various ways and to various degrees according to the parts concerned.

85. 1. **External secondary changes.**—In some cases the older roots differ from the younger in scarcely more than the

loss of the external layer of cells, from which the root-hairs arose. The sloughing off of this layer of cells carries with it the hairs themselves and exposes the next inner layer of cells, which had before become slightly altered so as to be rather impervious to water. Upon their exposure, this alteration proceeds further, so that they become almost or quite incapable of being penetrated by the soil-water to which they may be exposed. It follows from this that it is only the younger part of the root, that is, the portion which has not undergone secondary changes, which is capable of absorbing water. In many roots this is the only change which occurs. In a greater number certain tissues become thick-walled, so that the root is also strengthened.

In a few instances, the root-cap is cast off from the tip. This, however, only occurs when the growth in length of the root is permanently stopped.

86. 2. Internal secondary changes.—In a large number of roots, especially those of dicotyledons and gymnosperms, the secondary changes result in increasing the diameter, sometimes very greatly. Increase in diameter comes about by the formation of concentric layers of new tissue in two or more regions. The new cells are produced in each region by the resumption of active division in a layer of cells which had been temporarily inactive. This region is then called the *cambium* or *secondary meristem* (see ¶ 77). The divisions which ensue in these cells are in the main parallel to the surface of

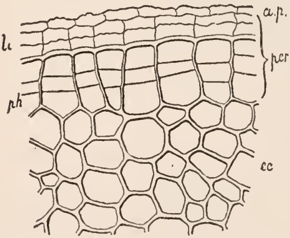


Fig. 87.—Transverse section of the periphery of the root of Clusia, showing the formation of periderm. *cc*, cells of cortex; *ap*, the superficial cells of the root (suberized); *per*, the periderm, its inner cells (opposite *per*) actively dividing by tangential walls, its two outer layers, *li*, suberized, its innermost layer, *ph*, the phelloderm. Highly magnified.—After Van Tieghem.

the root, that is, they are *tangential* divisions.

The outer growing layer or cork cambium is in the great majority of plants formed from the cells of the pericycle, but it may be produced by some of the cells of the cortex. In any case the tissues which arise from this division are of such a nature as to protect the parts within. They constitute the *periderm* (fig. 87),

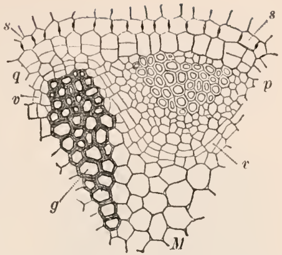


FIG. 88.—Transverse section of two bundles from the periphery of the stele of root of broad bean (*Vicia Faba*) at the beginning of secondary thickening. The xylem bundle, *g*, is shaded: the phloem bundle unshaded. *v*, the stelar cambium; *p*, the pericycle, also showing tangential divisions in parts; *s*, the endodermis. Highly magnified.—After Haberlandt.

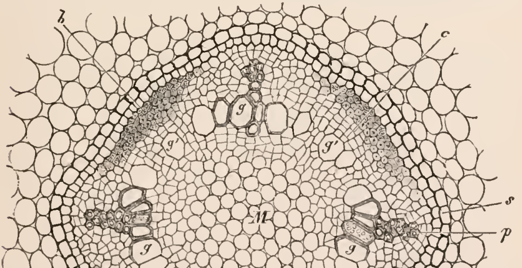


FIG. 89.—Transverse section of the stele of root of bean (*Phaseolus multiflorus*) shortly after secondary thickening has begun. *s*, endodermis; *pc*, pericycle; *b*, phloem bundles; *p*, primary xylem bundles; *g*, *g'*, secondary xylem; *c*, stelar cambium; *M*, central pith. Compare with fig. 90. Highly magnified.—After Sachs.

and are ordinarily cork-like, i.e., thin-walled and impervious to water. Those cells which lie outside a layer of cork are therefore cut off from a supply of food and soon perish.

The inner growing layer, or stelar cambium, is developed within the stele and follows a tortuous course, lying outside the xylem and inside the phloem bundles (fig. 88). As a result of tangential divisions in this region, tissues similar to those already existing in the stele are produced. On the outer side the cells differentiate mainly into the tissues of the phloem, and on the inner side mainly into those of the xylem, often forming a nearly unbroken mass of each (figs. 89, 90). The relative amount of the different tissues which make up these bundles goes far to determine the character of the mature root.

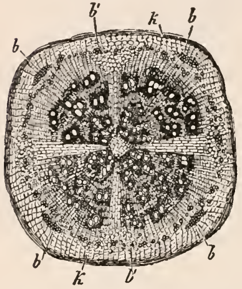


FIG. 90.—Transverse section of the older part of the main root of bean (*Phaseolus multiflorus*) after secondary thickening has progressed considerably. Compare with fig. 89, which is about five times as highly magnified. *b*, *b*, *b*, *b*, four primary phloem bundles; *b'*, secondary phloem produced by stelar cambium, as are the four wedges of secondary xylem. (Primary xylem bundles not shown. They lie next the pith between secondary xylem wedges.) *k*, periderm.—After Sachs.

87. (*a*) **Woody roots.**—If mechanical tissues predominate, particularly in the xylem, the root will become strong and rigid, as in the case of trees and shrubs. When the root is long-lived, the activity of this stelar cambium is usually resumed with each season, a layer of tissue being thereby added to the outside of the xylem region, and a thinner layer to the inside of the phloem. The woody part, especially, shows in cross-section concentric rings indicating the yearly additions. Since the material produced by the stelar cambium usually greatly increases the diameter of the root, the outside parts become fissured lengthwise. Thus, in an old and much-thickened root of the woody type, the periderm

and the phloem region, with the cortex between them, if anything is left of it, constitute a *bark*, which becomes furrowed lengthwise, like the bark of the stems of many trees. Such secondary thickening finally produces in the roots a

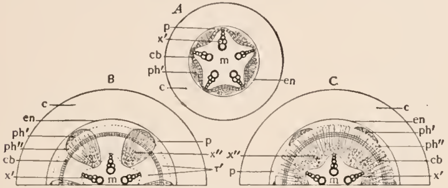


FIG. 91.—*A*, diagram of primary structure. *B*, *C*, diagrams showing the results of secondary thickening from the stelar cambium in the two extreme forms *c*, cortex; *en*, endodermis; *p*, pericycle; *ph'*, primary phloem; *ph''*, secondary phloem; *x'*, primary xylem; *x''*, secondary xylem; *cb*, stelar cambium; *r'*, secondary pith-rays; *m*, pith.—After Van Tieghem.

structure which is almost identical with that of stems which have undergone secondary thickening. (Compare ¶ 133.)

88. (*b*) **Fleshy roots.**—But if thin-walled cells are the predominant products of the stelar cambium, the root often becomes very thick and fleshy, as in the carrot, turnip, radish, sweet potato, beet, dahlia, artichoke, etc. Such roots serve the plant as storehouses of reserve food, and are consequently useful to animals as food. The thin-walled cells which are produced in such volume may belong to the phloem region, as in the carrot and parsnip, or to the xylem, as in the radish and turnip. This thickening for storage purposes may affect either the primary or secondary roots, or both. Other plants may develop the cortex (orchids) or the pith (daffodils) to an extraordinary degree, forming fleshy roots which also function as storehouses.

89. (*c*) **Float roots.**—In plants which grow in water or in very wet swamps, roots are sometimes modified to serve as floats. In these cases, the voluminous cortex consists of large

cells, with huge intercellular spaces which are filled with air. The root thus serves to buoy up the parts of the plant to which it is attached.

90. (*d*) **Tendrils, thorns, etc.**—In a very few plants, aerial roots are modified into *tendrils*, being slender, sensitive to contact, clasping the objects which they touch, if of suitable size, and thus assisting the plant to climb; in some instances they are altered into *thorns*, being short, rigid, and sharp-pointed; in others, being exposed to the light, they develop chloroplasts, which enables them to act as organs for the manufacture of food.

91. Branching.—Both primary and secondary roots may branch. The mode of branching is of two sorts, either by dichotomy, or by the production of lateral branches.

92. (*a*) **Dichotomy** occurs only in a few fernworts, whose roots possess a single initial cell. In this case, however, the single initial cell (¶ 77) is not divided into two equal parts by a partition-wall, as in true dichotomy (see ¶ 103), but the initial of the new branch arises from a very young segment as in Metzgeria (see fig. 61). The result is a forking which cannot be distinguished from a true dichotomy.

93. (*b*) **Monopodial branching.**—In the common mode of branching, the monopodial, the central axis grows most vigorously, and bears lateral branches upon its sides. The normal branches arise from lateral growing points, which originate in regular succession behind the apical growing point. But sometimes branches appear out of this regular order. Such are called adventitious roots. (See ¶ 76.)

94. Position.—Whether regular or adventitious, the position of the growing points is determined by the vascular bundles in the stele, since they originate opposite the xylem bundles, or with definite relation to them. (See figs. 92, 93.) The number of vertical ranks of branches can, therefore, be predicted with some certainty from the structure of

the root. While the angular divergence is thus quite regular, the longitudinal intervals at which the branches will be formed, which determines their distribution along the length of the root, are unequal (fig. 92).

When secondary roots arise from the shoot, they have a fixed relation to the leaves, or they are formed upon the buds produced in the axils of the leaves, or they may arise at indefinite points along the internodes. In the first case, roots may be produced either opposite a leaf, or in pairs, right and left of the base of the leaf.

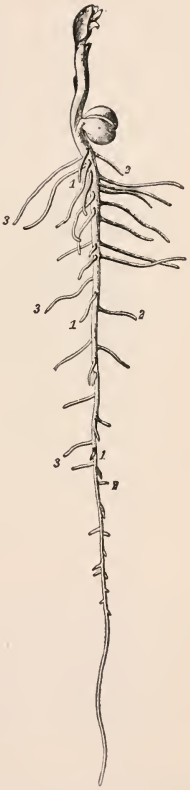


FIG. 92.—Seedling pea, showing three vertical ranks of branches along the main root. These are numbered 1, 2, 3. Natural size.—After Frank.

95. Origin.—The origin of root-branches and of secondary roots is rarely exogenous; that is, the root is not commonly produced by the division of cells which lie upon the surface of a member. In the great majority of cases the origin of the roots is endogenous; that is, the formation of the root is begun by the division of cells lying in the interior of the member producing it. In most cases these divisions begin very near to the surface of the stele, either just without it, in the endodermis, or just within it, in the pericycle. Soon a growing point is formed (fig. 93). The rootlet is thus in its early stage completely hidden, being buried

beneath the cortex, through which it gradually makes its way by the destruction of the tissues ahead of it, partly through disorganization of the tissues by pressure, and, probably, partly through actual digestion and absorption of the material of these cells. When the rootlet reaches the surface it emerges, therefore, from a distinct rift in the cortex (fig. 94).

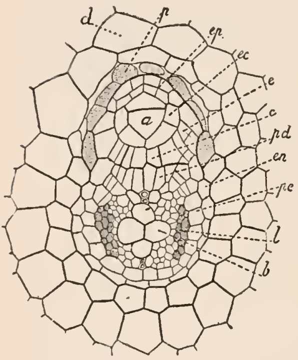


FIG. 93.

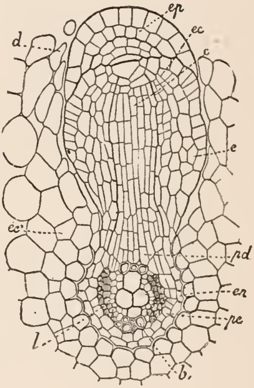


FIG. 94.

FIG. 93.—Transverse section of a root of a fern (*Pteris cretica*), passing through the axis of a rootlet which has not yet emerged. Only the stele and three rows of cortex shown. *a*, apical cell of rootlet, forming anteriorly the root-cap, *ep*, and posteriorly the body of the root, *ec*, *e*, *c*, *pd*; *b*, binary xylem bundles; *l*, phloem bundle with its fellow opposite; *pe*, pericycle; *en*, endodermis; *p*, temporary digestive pouch, in course of disorganization and digestion; *d*, cells of cortex, which will be disorganized as rootlet advances. Highly magnified.—After Van Tieghem.

FIG. 94.—The same as fig. 93, but older; not quite so much magnified. The rootlet is just emerging from the parent root. *pd*, *c*, stele of the rootlet; *ec*, its cortex; *d*, disorganized cells of cortex, *ec'*, of parent root; *b'*, secondary xylem; other letters as in fig. 93.—After Van Tieghem.

96. External conditions.—Branching of the root is often profuse, and is dependent very largely for its character upon the conditions under which it takes place. In those roots which penetrate the soil, it is profoundly modified by the

character of the soil itself and the amount of moisture and organic matter in it.

97. Buds.—New shoots may be formed by the roots, either as a result of injuries, or normally. In a partially developed form, these constitute *buds* (see ¶ 101). Whether formed as a result of injuries or normally, they are known as *adventitious buds.* They arise in the same places and develop in the same way as lateral roots; that is, they are endogenous, and, as they continue to grow, burst through the cortex. The shoots so produced grow in the normal manner. Very rarely the growing point of the root, casting off the root-cap, becomes itself the growing point of the shoot. This alteration is usually the result of artificial reversal of the position of the root, being brought about in some potted plants by turning them upside down.

CHAPTER VIII.

THE SHOOT.

98. The gametophyte shoot.—If plants could be examined in the order of their development, it would be discovered that the shoot has been evolved earlier than the root. It makes its appearance first in the leafy liverworts and in the mosses, in which the gametophyte and sporophyte each form a stem. The gametophyte differentiates its secondary shoot into a stem and leaves. This stem in liverworts is a slender cylindrical body of very simple structure, upon whose flanks arise leaves which consist of a single layer of cells only. (See ¶ 60.) Neither the stem nor the leaves are homologous with the stem and leaves of the higher plants. In the stem itself one finds all the cells practically alike, so that little differentiation of tissues has yet occurred. In mosses, however, the gametophyte stem shows some advance, in that its tissues are clearly differentiated, the outer being transformed into thick-walled cells, in order to give mechanical rigidity to the stem, while the innermost, remaining slender, are much elongated and serve the purpose, it may be, of conduction. (See ¶ 63.) This differentiation is naturally more marked in those mosses which are erect and whose body becomes largest, since in these the need for rigidity and conduction of food materials from one part to the other becomes greater. In both groups the branching of the gametophyte shoot is like that of the sporophyte shoot of some of the higher plants, except that the branches never stand in the same relation to the leaves. (See ¶ 65.)

99. The sporophyte shoot.—The shoot developed by the sporophyte of mosses and liverworts forms no leaves, but develops as a slender cylindrical stalk, at the distal end of which the capsule containing the spores is formed (figs. 64, 73). It is rather difficult to see in this cylindrical stalk the homologue of the leafy stem developed by the sporophyte of the fernworts and other plants.

The simultaneous performance of the work of nutrition and of sexual reproduction proved impracticable, as shown by the development of the liverworts and mosses, which are all humble plants. The fernworts, originating probably at an early period from the same ancestors as the liverworts, separated the two functions and laid the chief work of nutrition upon the sporophyte. The advantage thus gained enabled the extinct fernworts to develop into plants of tree-like size, and to become the ancestors of all the seed plants.

The gametophyte shoot was, comparatively, a failure; the sporophyte shoot was a marked success. It has become adaptable to many conditions and many functions. To accomplish this its members have been extensively modified in form and structure in various plants. The development and mode of branching, together with the various forms which the shoot assumes, are now to be discussed, to be followed by an account of the two members, stem and leaf, into which it is usually differentiated.

100. Primary shoot.—The shoot which develops from the fertilized egg is called the *primary shoot*. A very few exceptional plants are found in which no primary shoot develops, although there are a number of cases in which the primary shoot becomes early aborted, and its place taken by secondary shoots arising from the root. The primary shoot normally arises in fernworts from the anterior half of the egg. The anterior hemisphere usually divides into two quadrants, one of which develops into the primary leaf, and the other into

the primary stem. The stem quadrant, by repeated divisions, quickly specializes a central cell, which becomes the apical cell of the new shoot. Ordinarily it takes the form of a three-sided pyramid, whose base forms the extreme tip of the developing shoot (*s*, fig. 76, *t*, fig. 95). From the three inner faces, as described for the root (¶ 77), segments are constantly formed, whose further divisions produce all the tissues which constitute the members of the mature shoot, i.e., the stem and the secondary leaves. In some fernworts and in the seed plants, the posterior hemisphere resulting from the first division of the egg grows into a filament called the suspensor, and the primary shoot develops from the anterior hemisphere. (See fig. 80.) In these plants ordinarily two or more cells at the apex of the primary shoot are specialized as the initial cells, and from their segmentation arise the tissues of the whole shoot, as in the fernworts.

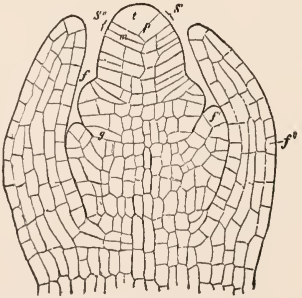


FIG. 95.—Median longitudinal section through the apex of a shoot of the horsetail (*Equisetum arvense*), showing primary meristem and the form of the growing point. *t*, apical cell, from which a segment, *S'*, has just been cut off by wall *p*. *S''*, a segment previously cut off, has divided by wall *m*. *f*, *f'*, *f''*, successively older leaf fundaments; *g*, the initial cell of a branch. Magnified 160 diam.—After Strasburger.

101. Primary meristem.—Whether the tip of the shoot be occupied by a single initial cell or by a group of initials, the apical region, in which the formation of new cells is

taking place, is called the *primary meristem* (fig. 95). This primary meristem has no definite limit below, but passes insensibly into the permanent tissues. The tip of the shoot may be either a sharp cone or a low dome. Between these forms a complete series of gradations exists. Below the apex the shoot begins to show a differentiation into a central axis and lateral outgrowths. The first of these to appear are swellings which form the leaves. Later, above the leaf fundaments may appear the fundaments of the lateral shoots.

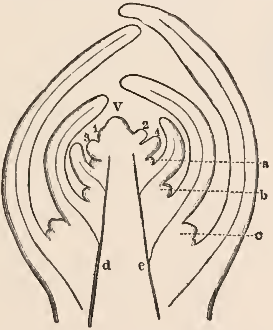


FIG. 96.—Diagram of a section through a bud. *V*, the apex; 1, 2, 3, 4, successively older leaf fundaments; *a*, *b*, *c*, successively older branch fundaments; *d*, *e*, vascular bundles. —After Hansen.

The older leaves upon the sides of the axis outgrow the younger ones and the developing axis, and arch over them in such a way as to form a more or less compact structure, which is a *terminal bud*. A bud is, then, an undeveloped shoot, whose older leaves protect the younger, and particularly the primary meristem (fig. 96). From the terminal bud arise all the members of the primary shoot.

102. Differences from root.—From what has been said of the origin of the shoot, it will be observed that it is dis-

tinguished from the root by not forming through segmentation from the outer faces of the initial cell or cells a many-layered epidermal cap. In further contrast with the root, which often has no true epidermis except the root-cap, the shoot is characterized by possessing an uninterrupted epidermis over its entire surface, consisting always at first of a single layer of cells. This epidermis persists as a surface covering either throughout the life of the shoot, or for a long period, being replaced only upon the older surfaces of the axis by subsequently formed protective layers. (See ¶ 134.)

FIG 97.—Shoot of European linden. *t*, the last internode formed by the bud of present season. This dies and drops off and the shoot will be formed next year by the last axillary bud, *a*, which appears to be terminal after loss of *t*. Half natural size.—After Frank.

103. Branching. — Branches of the shoot arise from lateral buds, which are in all respects similar to the terminal buds just described. If, for any reason, the terminal bud of the stem becomes destroyed, or its growth arrested, a branch, developing from a lateral bud near by, may assume the position and habit of the main axis, its own normal mode of development being altered. In many plants the death or arrest of the terminal bud recurs at regular intervals. In such plants, therefore, the main axis is really a succession of lateral branches, and the branching is said to be *sympodial* (fig. 97). In some plants, e.g., lilac, two lateral buds standing at the same level may develop, if the terminal one fails. In this case the shoot seems to divide into two equal branches. This, however, is not true, but *false*, or *sympodial, dichotomy*. True dichotomy, like true dichotomy of the root, occurs only in those plants in which the axis has

a single initial cell. The initial in these cases divides into two equal parts, each of which becomes the initial of a new branch. Ordinarily, however, the terminal bud develops without interruption. In case it is more vigorous than any of the lateral buds, the plant will have a central axis, from the sides of which distinctly smaller branches arise. If, however, the lateral buds are almost or quite as strong as the central one, the plant seems to be broken up into branches, and, after it has attained its mature form, no one can be pointed out as the main axis.* Such branching is *monopodial*. These two types of monopodial branching and the sympodial type are all illustrated in the forms attained by common forest trees. (See frontispiece.)

104. Inflorescence.—Especially profuse branching commonly occurs in the parts of the seed plants where flowers are produced. Such clusters of branches bearing flowers constitute an *inflorescence*. Each sort has received a special name which not only indicates the type of branching, whether sympodial or monopodial, but also the relative length of the branches.

If the branching is monopodial and each lateral shoot is unbranched, the inflorescence is a *raceme*. If the lateral shoots are very short, it is a *spike*. If the main axis also is very short, it is a *head*. If the main axis is short and the lateral axes long, it is an *umbel*. If the lateral axes are of unequal length, so as to bring the flowers to about the same level, it is a *corymb*. If the branching is sympodial, various forms of the *cyme* result. Several combinations of these inflorescences are possible.†

105. Axillary buds.—Lateral buds are ordinarily formed in definite relation to the leaves. They stand usually in the

* The obscurity is greatly increased by the death of more branches than survive, owing to various causes resulting in poor nutrition or disease.

† For further discussion see Gray: "Structural Botany," p. 144; Goebel: "Outlines of Classification," p. 407.

upper angle formed by the leaf with the stem. This angle is known as the axil of the leaf, and such buds are said to

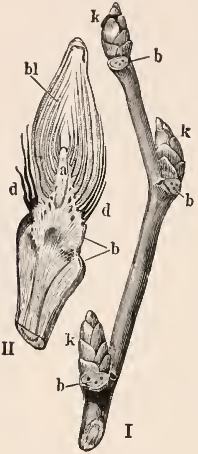


FIG. 98.

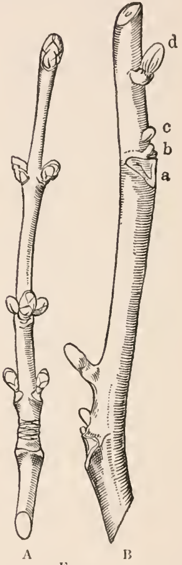


FIG. 99.

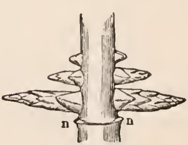


FIG. 100.

FIG. 98.—I, terminal shoot of an elm. *b*, leaf-scars; *k*, axillary buds. Natural size. II, one of the buds cut lengthwise through center, magnified 3 diam. *a*, young axis; *b*, leaf-scar; *bl*, young leaves; *d*, bud-scales. —After Behrens.

FIG. 99.—*A*, twig of red maple with accessory buds in addition to axillary bud. *B*, twig of butternut, with leaf-scar, *a*, small axillary bud, *b*, and larger accessory buds, *c*, *d*, above axil. Natural size.—After Gray.

FIG. 100.—A bit of stem of a honeysuckle (*Lonicera xylosteum*) bearing large axillary and smaller superposed accessory buds above the axils of the scars, *n n*, from which leaves have fallen. Natural size.—After Frank.

be *axillary* (fig. 98). Ordinarily a single bud arises in the axil of each leaf. Its origin is always subsequent to that of the leaf-fundament (figs. 95, 96).

There are many cases in which the lateral buds are not found precisely in the axils of the leaves, but slightly to one side, or at a greater or less distance above the axil (figs. 99, 100).

106. Extra-axillary buds.—Buds are frequently formed without any relation whatever to the leaf-axil, and even on the leaf itself (fig. 293). Sometimes these extra-axillary buds are produced without the action of any extraordinary cause, but more commonly injury of one sort or another seems to act as a stimulus to the production of such buds. Buds which do not originate in acropetal succession on the parent shoot are called *adventitious* buds.

107. Adventitious buds may arise upon stems, leaves, or roots. They are most commonly and abundantly produced upon stems and roots. In the willows their ready production is utilized for obtaining young, vigorous, and pliable shoots to be used in basket-work. The few plants which produce adventitious buds upon leaves, as well as the many which produce them on stems, are often propagated in this way. (See ¶ 364.)

108. Dormant buds.—Many buds continue to grow without interruption from the time of their formation, but more cease to develop after they have reached a certain stage. Such buds may remain dormant for a considerable period, and may even be overgrown and completely enclosed by the wood upon old shoots. The bud in this case grows slowly and maintains itself near the surface of the wood. It is quite possible that these dormant buds should for some reason begin to develop later, when they are liable to be confounded with adventitious buds. In case they have been buried by the growth of tissues over them, the shoot which they produce will seem to come from the interior of the organ upon which they are borne. This apparent internal origin must not be confounded with the real endogenous origin of roots.

Since in most cases lateral buds have a definite relation to the leaves, the shoots which arise from them will have a similar relation. But, since many buds are produced which never develop into branches, this relation is often obscure and difficult to see.

109. Special forms.—The primary shoot may grow underground, in which case its stem usually takes a horizontal direction and becomes much thickened for storage of reserve food (¶ 236), while its leaves are so reduced as to be scarcely recognizable. Such a shoot is known as a *rhizome*. When the primary stem is short, erect, and crowded with thickened leaf bases it forms a *bulb*, as in the hyacinth and onion. When the primary stem is short and thick, and has thin scale leaves upon it, it forms a *corm*, as in cyclamen and Indian turnip.

Branches of the specialized primary shoot may be like it, as when some branches of the rhizome or corm are themselves rhizomes or corms. Others, however, will be adapted to other purposes, as when aerial branches arise from rhizomes to carry foliage and flowers, or when slender leafless shoots called *runners* develop from the main axis of the strawberry (fig. 297). *Offsets* and *stolons* (figs. 296, 369) are similar branches likewise adapted to propagation (¶ 366).

Branches of the secondary shoots may also be different from their parent axis. In different plants the shoots assume the most varied forms.

Such specialized branches may be confined to a definite region of the plant, or may be distributed over it. The more important of these kinds of branches may now be enumerated.

110. (*a*) **Dwarf branches.**—It is not uncommon to find branches specialized merely by their slight development in length and their capacity for being separated readily from the parent shoot. Such short branches are particularly com-

mon among the cone-bearing trees. In these plants the short branches carry the clusters of needle leaves (figs. 101,

FIG. 101.—A shoot of Scotch pine showing two regions of dwarf branches each with a pair of needle leaves, and three regions of flower branches; the flowers have fallen from lower two, showing scale leaves covering the stem. Natural size.—After Willkomm.

102, 358). After the death of the leaves the branches themselves drop off. Somewhat similar short branches are

to be recognized among many deciduous trees, and, in the apple, the so-called fruit spurs are not dissimilar (fig. 103).

111. (*b*) **Flowers.** — The most common of the specialized branches among the seed plants are those which constitute the flower. In these the axis usually remains short, the leaves are crowded, and often

FIG. 102.

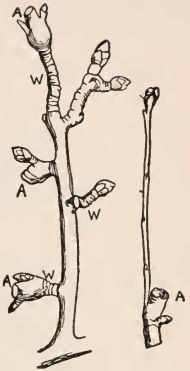


FIG. 103.

FIG. 102.—The base of leaves and dwarf branch of Scotch pine cut through the center lengthwise. Besides the two needle leaves the dwarf branch carries a number of scale leaves, *d*. Between the bases of the needle leaves is seen the conical apex of the dwarf branch, showing their lateral origin. Magnified about 4 diam.—After Luerssen.
FIG. 103.—Twig of apple, bearing fruit spurs. *A*, points at which fruit was detached the preceding year; *W*, leaf scars. Natural size.—After Hardy.

some of them are highly colored (fig. 104). Commonly these flower branches are deciduous.

FIG. 104.

FIG. 105.

FIG. 104.—Flower of *Sedum acre*. *s*, sepal; *p*, petal; *st*, stamen; *c*, carpel. Magnified 3 diam.—After Baillon.
FIG. 105.—Piece of a twig of asparagus; in the axil of the scale leaf, *b*, arise a flower shoot, and three leafless needle-like branchlets. Magnified about 2 diam.—After Frank.

112. (*c*) **Cladophylls.**—A few plants have developed shoots which replace leaves in function and resemble them

in form. These *cladophylls* may be either broad and flattened, as in the "smilax" of the greenhouses, or they may be slender and needle-like, as in the common garden asparagus (fig. 105). In any case, since they replace leaves in function, they are abundantly supplied with green coloring matter for manufacturing food.

113. (*d*) **Bulblets.**—Other branches remain undeveloped as buds, but their leaves become thick and fleshy. These bulblets are easily detached and serve for propagation. (See ¶ 364.) They are to be found in many plants. In the tiger-lily they occupy the axils of the leaves (fig. 294), and are modified lateral buds, while in the garden onion they usually replace the flowers.

114. (*e*) **Tubers.**—Some underground shoots have their ends suddenly and greatly enlarged, adapting them to the storage of food. They are then called tubers. In the white potato the tuber consists of several terminal internodes of an elsewhere slender underground stem, the "eyes" being lateral buds in the axils of minute scale leaves. In a few plants tubers may even be formed above ground, as in certain polygonums whose flowers are often replaced by little tubers which are readily detached (fig. 106).

115. (*f*) **Tendrils.**—Some shoots take the form of slender, leafless, sensitive tendrils, which assist the plant in climbing by coiling about suitable objects (fig. 107).

116. (*g*) **Thorns.**—Many plants produce defensive shoots, which are leafless, rigid, short, and sharp, called thorns, which may be either simple or branched (fig. 108). The honey-locust furnishes an excellent example of branched, or compound, thorns.

Leaves themselves may be developed as tendrils or as thorns, so that it must not be assumed from appearance alone that such members are forms of the shoot. Observation of the origin and relation of the members will reveal their true

nature. If shoots, they will usually be subtended by a leaf; if leaves, they will often have a bud or a shoot in their axils. Thorns or tendrils which do not arise at the nodes are reckoned as shoots.

117. Duration.—Shoots are either annual, biennial, or perennial. If the entire shoot dies

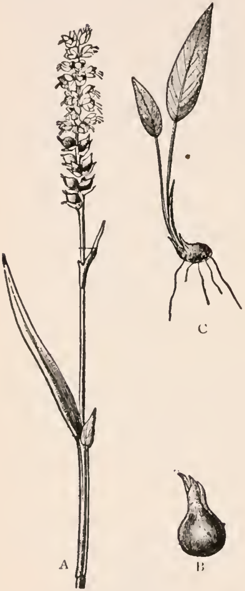


FIG. 106.

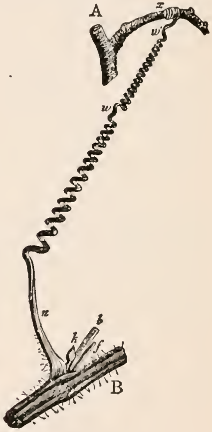


FIG. 107.

FIG. 106.—*A*, upper part of a plant of *Polygonum viviparum*, showing flower cluster, the flowers in lower half being replaced by tubers. Two-thirds natural size. *B*, a fallen tuber. Magnified about 3 diam. *C*, a plantlet growing from tuber. Natural size.—After Kerner.

FIG. 107.—A portion of the stem of white bryony, *B*, from which a tendril, *ux*, arises near the leaf stalk, *b*, and the bud, *k*. *u*, rigid portion of tendril; the portion between *u* and the portion *x*, clasping the support, *A*, has become coiled into a spiral which reverses the direction of the coils at *w* and *w′*. Nearly natural size.—After Sachs.

this generally involves the death of the whole plant, though new adventitious shoots may arise from the roots, as in sweet potatoes. In many plants, in which the shoot seems

to die at the close of the growing season, an underground portion really survives, and sends up the new shoots. Such plants, if they live for two years, are called biennials; or, if they live for several or many years, are called perennials.

FIG. 108.—Shoots of *Vella spinosa*, showing thorns. Natural size.—After Kerner.

The shoot may be composed mainly of soft tissues, and persist underground, where it is protected against unfavorable conditions, such as drought and cold, and especially against sudden changes; or it may be composed mainly of mechanical tissues, and be fully exposed, as are the shoots of trees. In these cases the leaves generally perish and drop off annually, but in the "evergreen" plants they live more than one growing season.

CHAPTER IX.

THE STEM.

118. Definition.—The shoot is almost always segmented into members of two kinds, the stem and leaves. The stem is the central axis of any shoot, and the leaves are lateral outgrowths, or branches, of it. These two members cannot be accurately defined, but are in most cases readily distinguishable. Leaves commonly differ from the stem in internal structure, and in their flattened form, limited growth, and position, subtending the lateral shoots. (See further p. 117.)

119. Nodes and internodes.—Upon examining the surface of the stem, it is almost always readily distinguishable into distinct regions, the nodes and internodes. The nodes are the narrow zones, often somewhat swollen (whence the name), at which one or more leaves arise. The internodes are the zones between the nodes. Upon watching the development of the stem from the terminal bud, it will be seen that new nodes and internodes are constantly emerging from its base, and that the leaves formed at the nodes are successively expanding. This emergence of the internodes is due to their elongation. The amount of elongation, however, varies greatly in different plants, and even in different parts of the same plant. In many cases the internodes are considerably and uniformly elongated; the leaves are then distributed along the stem at considerable and regular intervals. In other cases the internodes remain very short, and the leaves are,

therefore, crowded. They may be so crowded as to completely envelop the stem and hide it from view. This is well seen in the scale-like leaves of such plants as the pines (fig. 101), cedars, and arbor vitæ (fig. 109). Or, certain of the internodes may elongate, while others remain undeveloped. For example, in the shepherd's-purse, the first internodes remain short, so that the lower leaves are crowded into a tuft or rosette; the following internodes are elongated, the corresponding leaves being scattered at regular intervals; while, still higher, the internodes are again shortened and the leaves brought into close clusters in the flowers.

FIG. 109.—A shoot of arbor vitæ or white cedar, showing scale leaves covering stem. Natural size.—After Kerner.

120. The consistence of the stem depends upon the relative amount of mechanical tissues which it contains. Stems may be designated as woody, solid, or fleshy, terms which need no further definition.

121. The shape of the stem varies extremely in different plants. Very commonly the stem as a whole is looked upon as cylindrical, but, if carefully considered, it will be seen that the diameters of successive internodes at first become gradually greater, and, after maintaining this maximum for a time, grow gradually less. The stem is, therefore, a cylinder with more or less conical ends. If the attainment of the maximum diameter is sudden, and the diminution similarly sudden, the resulting stem will have the shape of a double cone. The modification of such a form into the spherical is not difficult to imagine. Striking illustrations of these extreme forms are to be found among the cactuses (fig. 110).

122. A section of the stem commonly presents an irregularly circular outline (fig. 111). Occasionally the surface of the stem is fluted or channeled, and, if these grooves or channels be few and the corresponding angles prominent, the section of the stem is polygonal, with three, four, five, six, or more sides.

123. Habit.—As to habit, stems are commonly *erect* when enough mechanical tissue is developed to render them sufficiently rigid to carry not only their own weight, but that of

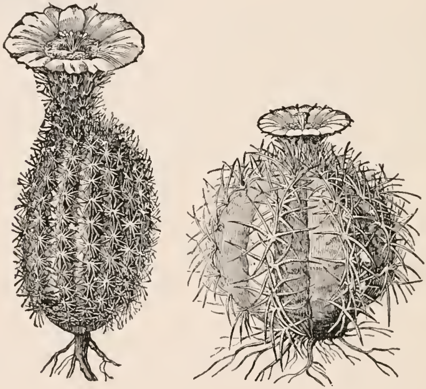


FIG. 110.—Cactuses, showing form. *A*, *Cereus dasyacanthus*. *B*, *Echinocactus horizontalis*. In both the clusters of spines arise from tubercles on the stems. Reduced.—After Kerner.

the leaves and other members attached to them. Other stems lie flat upon the ground, to which they may or may not attach themselves by the development of secondary roots. Between these *prostrate*, or *creeping*, stems and the erect form every conceivable position exists. The direction of growth is determined largely by the relation of the plant to gravity and light as stimuli. (See ¶¶ 285, 287.) Other stems rise into the

air, not by their own rigidity, but by the development of special members for climbing purposes, such as recurved spines, tendrils, sensitive leaf stalks, or even by recurved normal branches. (See ¶¶ 115, 158.) Others wrap themselves about objects of suitable size, and are called twining stems. (See ¶ 291.) The direction of twining varies with different plants, but most commonly corresponds to the movement of the hands of a watch, the support being supposed to be in the center.

124. Primary structure.—The origin of the stem-tissues has already been described. (See ¶ 100.)

In following the stem from apex to base it is readily observed that the structure changes as the parts grow older. It is possible, however, to select a point at which the stem in

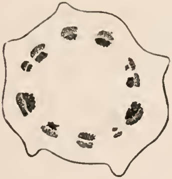


FIG. 111.

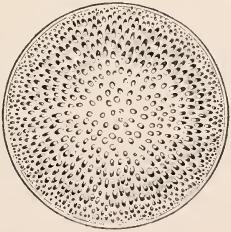


FIG. 112.

FIG. 111.—Diagram of a transverse section of stem of *Iberis amara*, showing outline, and paired vascular bundles. The black is the xylem bundle; the gray is the phloem bundle. The outer line represents the epidermis; a circle including the bundles would mark the limits of the stele, with its central pith; the cortex lies between the epidermis and stele.—After Nägeli.

FIG. 112.—Diagram of a transverse section of a palm stem. The epidermis is represented by the outer line; the endodermis by the inner one, with the narrow cortex between them; the stele, with numerous bundles scattered through the pith, is within the endodermis.—After Frank.

all cases attains a definite development. This point is at the internode which has just reached its full length. The structure of the stem at this point may be designated as its *primary structure*. If a thin section be cut from such an internode,

three definite regions may be distinguished, viz.: (1) the *epidermis;* (2) the *cortex;* (3) the *stele* (figs. 111, 112).

125. 1. **The epidermis.**—This is a single layer of cells forming the extreme edge of the section, being, therefore, the layer which covers the surface of the stem. Here and there may be observed intercellular spaces, which permit communication between the outside air and similar spaces in the deeper tissues of the cortex. These openings are usually bordered by two specialized cells, and are called stomata. The epidermal cells may be furnished with green chlorophyll bodies, or these may be entirely absent.

126. 2. **The cortex.**—This region consists of several rows of cells, usually thin-walled and not in close contact, and hence abundantly provided with intercellular spaces. These cells usually contain many chlorophyll bodies, to which the green color common to stems is due.

The innermost layer of the cortex abutting upon the stele, whose radial walls are suberized (¶ 9), is usually specialized to form a distinct layer of cells. This layer is the *endodermis* (fig. 118).

127. 3. **The stele.**—The central region is called the stele. It consists, as in the root, ordinarily of three parts. Its outer layer of cells is known as the *pericycle* (fig. 118). Within the pericycle are clusters of smaller cells, the cut ends of the vascular bundles. Occupying the space between the vascular bundles is the pith (figs. 111, 112).

These regions of the stem are subject to various modifications.

128. 1. **The epidermis.**—While the epidermis is usually a single layer of cells, it is sometimes increased to two or three layers. Stomata may be entirely lacking. This is especially the case in those underground and submerged stems in which the stomata would be useless. The cells of the epidermis are often prolonged into outgrowths of various

shapes, such as *hairs, scales,* and the like (figs. 113, 114; see also figs. 361–365).

129. 2. **The cortex.**—In some plants the cortex undergoes an enormous development, forming in some tubers the greater part of the massive stem. In other plants the cortex undergoes such reduction that it consists only of two or three layers of cells. It very commonly enters with the epidermis into the formation of outgrowths, which are then known as *emergences.* These emergences may take the form of rounded elevations, producing a warty stem, or they may be sharp pointed and either straight or curved, forming prickles (figs. 115, 116); or the emergence may be produced along a continuous line, giving rise to wings upon the stem; or the stem may be more or less covered with large pointed or angular elevations, called tubercles, as in some cactuses (fig. 110). Very frequently the intercellular spaces of the cortex are greatly enlarged, forming air passages of considerable size. These passages may arise by mere separation of the cells of the cortex, or by the destruction of those in certain regions, or by a combination of these causes (fig. 117). In other cases the cortical cells, instead of

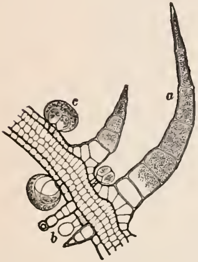


FIG. 113.

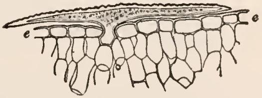


FIG. 114

FIG. 113.—Forms of hairs from *Plectranthus*. *a*, simple pointed hair; *b*, stalked glandular hair; *c*, sessile glandular hair with secretion covering the two glandular cells. Highly magnified.—After De Bary.

FIG. 114.—T-shaped hair of the wall-flower (*Cheiranthus*). *e*, epidermis. Highly magnified.—After De Bary.

remaining thin-walled, may become greatly thickened in certain regions, or even throughout the cortex. These

FIG. 115.

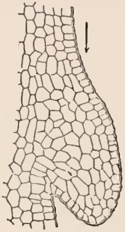


FIG. 116.

FIG. 115.—Prickles on the stem of a rose. Natural size.—After Prantl.
FIG. 116.—A longitudinal section through a rose prickle in a young stage, showing how the sub-epidermal (cortical) tissues enter into the structure of the emergence. Magnified 200 diam.—After Rauter.

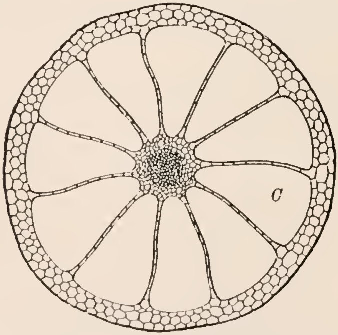


FIG. 117.—Transverse section of the stem of Elatine, showing intercellular canals, *c*. Magnified about 15 diam.—After Reinke.

mechanical cells are likely to be aggregated in clusters or strands, and serve an important purpose in strengthening

the tissues (fig. 118). In some cases vascular bundles are found in the cortex outside the stele, when they are known as cortical bundles.

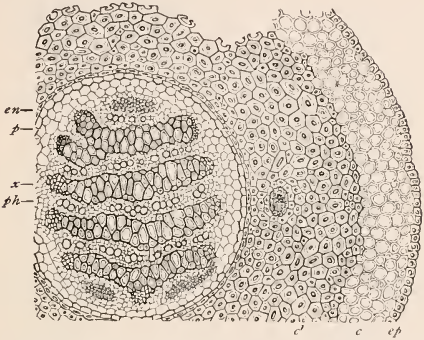


FIG. 118.—Transverse section of the stem of a ground pine (*Lycopodium complanatum*). The stele is enclosed by the endodermis, *en*; *p*, pericycle; *x*, xylem bundle; *ph*, phloem bundle; *c c'*, cortex, *c'*, mechanical tissue with thickened walls; *ep*, epidermis. In the cortex a branch stele passing out to a leaf on the right is cut across. Magnified 100 diam.—After Sachs.

130. 3. **Stele.** (*a*) **Pericycle.**—The pericycle is rarely wanting. It is much more frequently increased from one to several layers of cells. In this case it commonly differentiates into regions of mechanical cells with thick walls and small cavities and a region of thin-walled cells. These mechanical cells are either aggregated in strands opposite to the vascular bundles of the stele, or they constitute a complete zone around it. Many of the most valuable textile fibers, such as those of flax, hemp, and ramie, are obtained from this region of the stem (fig. 119).

131. (*b*) **Vascular bundles.**—In any section of the stem the number of vascular bundles in the central cylinder varies greatly, not only in different plants, but even in different parts of the same plant. The bundles are commonly arranged

in pairs, a phloem (bast) bundle and a xylem (wood) bundle being placed side by side, the xylem occupying the side next

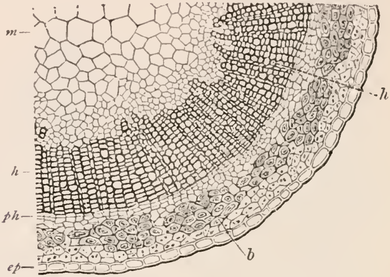


FIG. 119.—Portion of a transverse section of the stem of flax. *m*, pith; *h*, secondary xylem forming a woody cylinder; *ph*, phloem; *b*, bundles of mechanical tissue (fibers) among the thin-walled cells, the two sorts making up the cortex; *ep*, the epidermis. Magnified about 25 diam.—After Frank.

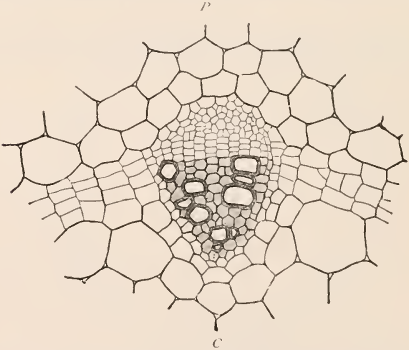


FIG. 120.—Transverse section of a bundle pair from the stem of a begonia. The shaded part is the xylem bundle; the small irregular cells above are the phloem bundle; between them is a zone of generating tissue (secondary meristem), the stelar cambium, which extends also right and left of the bundle pair. The radius of the section passes through *CP*; *C*, next the center. Magnified 150 diam.—After Haberlandt.

the center of the stem, and the phloem the side next the surface (figs. 111, 120). The number and position of these

bundles is, however, subject to change. In some cases one of the strands surrounds the other. Commonly it is the bast which surrounds the wood, as in the fernworts (fig. 121). Sometimes independent phloem bundles are

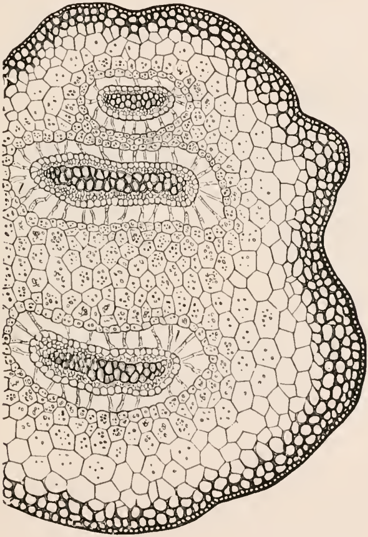


FIG. 121.—Transverse section of *Selaginella*, showing three steles, each composed of a xylem bundle surrounded by phloem. *l*, *l*, intercellular spaces in cortex, separated from the steles only by the large-celled endodermis. The cells underlying the epidermis are thickened to form mechanical tissue. Magnified 150 diam.—After Sachs.

found with which are associated no xylem bundles. In the phloem certain cells may develop into fibers, which are not to be confused with the fibers occurring in the pericycle. Some of these, also, are valuable in the textile industries.

The paired vascular bundles within the stele occupy various positions, and for purpose of location may be spoken of as though single. If transverse sections of the stem are observed, they may be seen either in a single row, roughly parallel with the surface of the stem (fig. 111), or in several concentric rows (fig. 122), or they may be irregularly disposed throughout it (fig. 112). No one method of arrange-

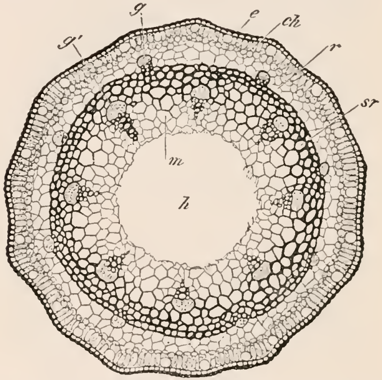


FIG. 122.—Transverse section of the aerial stem of an onion (*Allium Schoenoprasum*). *e*, epidermis; *ch*, chlorophyll-bearing tissue of cortex; *r*, colorless tissue of cortex; *g*, *g'*, vascular bundles (xylem bundles black, phloem bundles dotted); *sr*, mechanical tissues connected into a cylinder; *m*, pith; *h*, pith canal formed by destruction of cells, Magnified 30 diam.—After Sachs.

ment is confined to any of the larger groups of plants, although the first is characteristic of most dicotyledons, while both the second and third methods are common among the monocotyledons.*

* So many exceptions are found to these last statements that it is best not to indicate the arrangement of the bundles by the terms dicotyledonous or monocotyledonous, as has been commonly done; nor is it possible to maintain the terms exogenous and endogenous, which have long since become obsolete because misleading.

132. (*c*) **Pith.**—The pith likewise varies greatly in different plants according to different conditions of growth. It is frequently found enormously developed in those parts of the stem which are used by the plant for storing its reserve food, as in some tubers, such as the white potato and the yam. In other plants, particularly those growing in water, it suffers extreme reduction or is often completely wanting, in which case the bundles of the stele are in close contact, and the cortex usually shows a corresponding increase. In other plants the cells constituting the pith are greatly thickened, so as to form a mechanical tissue. The thickened areas are usually either opposite the bundles, forming a strand closely adherent to their inner faces, or they may extend to the flanks of the bundles, thus forming an arc embracing each. Sometimes the thickened region becomes extended between the bundles and joins the corresponding mechanical tissues in the pericycle, or even those of the cortex, so as to enclose completely the individual bundles (fig. 123). In other plants the pith dies early and shrivels up. Very large canals may thus be formed through it, or it may even disappear entirely (fig. 122). Such early disappearance of the pith produces the hollow stem characteristic of the grasses, the sedges, and the various members of the sunflower family.

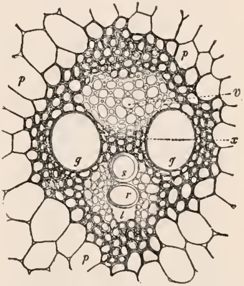


FIG. 123.—Transverse section of a bundle-pair of Indian corn. *v*, phloem bundle; *x*, *g*, *g*, *s*, *r*, xylem bundle; *p*, pith; *l*, an intercellular space formed by the tearing of some of the xylem tissues. The bundle pair is surrounded by a sheath of thick-walled mechanical tissues. Magnified 235 diam.—After Sachs.

133. Secondary structure.—Some stems retain throughout their entire existence the primary structure which has just

been described, undergoing only slight changes in the characteristics of the individual tissues which compose it. Thus, with age, there may be a thickening of the tissues so as to impart greater rigidity; or the waterproofing of the exterior may be made more perfect. These and similar changes do not, however, materially alter the structure. This permanence of primary structure is particularly frequent in the stems of monocotyledonous plants. It has been observed also in some dicotyledonous plants; for example, in the white water lily. But the stems of the great majority of dicotyledonous plants, as well as the conifers, quickly lose their primary structure, adding tissues of considerable amount, so as to bring about a more or less striking rearrangement of the first formed tissues (fig. 124).

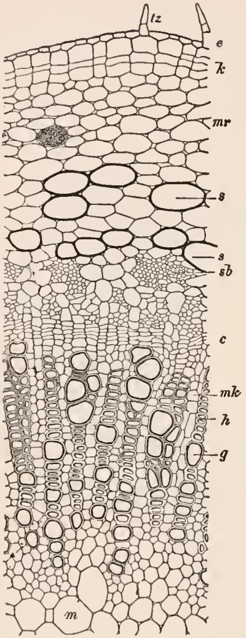


FIG. 124.—Part of a transverse section of a young stem of cinchona in process of secondary thickening. *tz*, hairs; *e*, epidermis; *k*, cork cambium; *mr*, cortex; *s*, gum-resin tubes in cortex; *sb*, primary phloem bundle; *c*, stelar cambium; *g*, *h*, secondary xylem; *mk*, pith rays; *m*, pith. The tissue between *sb* and *c* is secondary phloem. Highly magnified.—After Tschirch.

134. Secondary meristem.—This modification of the structure of the stem is due chiefly to the formation of one or two layers of actively dividing cells, which constitute secondary meristem or cambium, roughly parallel to the surface. When there are two, one of

the layers of cambium arises nearer the center, the other nearer the periphery of the stem. They are formed from existing cells which resume their power of active growth and division. The development of the tissues from the external meristem, or cork cambium, results in the formation of the *periderm*, while the tissues arising from the internal meristem, or stelar cambium, form the *secondary xylem* and *phloem* (fig. 124).

135. I. **The formation of secondary cortex.**—As the cells of the external meristem divide, sometimes the outer segments and sometimes the inner ones differentiate into permanent tissues, while the other segment remains as an initial for the next division. Some of the secondary tissue thus produced lies outside of the generating layer, and some inside (fig. 127). The secondary tissues, as a whole, constitute the periderm.

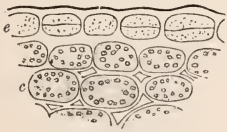


FIG. 125.

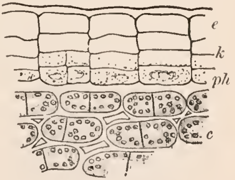


FIG. 126.

FIG. 125.—A bit of a transverse section of a young stem of *Scutellaria splendens* at the beginning of the formation of periderm. *e*, epidermis, some of its cells divided by tangential walls. *c*, cortex. See fig. 126. Highly magnified.—After Haberlandt.

FIG. 126.—Same as 125 but older. *e*, outer half of epidermal cells; *k*, cork cells formed by tangential divisions of inner half of epidermal cell (fig. 125) which has become *ph*, the cork cambium; *c*, cortex. Highly magnified.—After Haberlandt.

136. Periderm.—The tissues formed inside the cambium (*phelloderm*) are usually similar to the cells of the primary cortex. They form intercellular spaces, and retain their living contents, among which chloroplasts are often present. With the thickening of the outer tissues, however, these usually disappear.

The outside tissues of the periderm rarely remain living. No intercellular spaces arise between the flat cells, which early lose their contents, while the walls become waterproof. Such a tissue is known as *cork* (fig. 128). Other cells may be altered into *mechanical tissues* by the thickening of their walls and the death of the protoplasm. Zones of cork often alternate in the periderm with zones of mechanical tissues Since no water solution can pass through a cork zone, it is evident that all parts lying outside of one are cut off from a supply of nourishment, and must therefore perish sooner or later.

137. Location of cork cambium.—How much will thus be killed depends upon the position of the layer of cells which

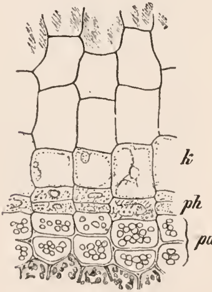


FIG. 127.

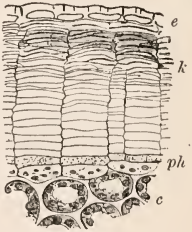


FIG. 128.

FIG. 127.—Part of a transverse section through the cork cambium and the tissues it produces in the European elm. *k*, cork cells, the innermost layer still with some protoplasmic contents; *ph*, cork cambium; *pd*, secondary cortex. Highly magnified.—After Haberlandt.

FIG. 128.—Part of a transverse section of young stem of cherry, showing formation of periderm. *e*, epidermis; *k*, cork; *ph*, cork cambium, with one row of secondary cortex below; *c*, cortex. Highly magnified.—After Haberlandt.

becomes the generating layer. It may be formed in one of three places: (*a*) It is sometimes in the epidermis itself (fig. 125), in which case only the outer half of the epidermal

cells will be sloughed off.* (*b*) In a majority of cases the generating layer of the periderm is formed in the cortex, either immediately under the epidermis (fig. 128) or in one of the deeper layers (fig. 127). (*c*) In other instances the generating layer is formed in the pericycle. If the pericycle is more than one layer of cells thick, it may be formed in the innermost or in any one of the external parts. In this case, therefore, there will be killed all the tissues of the cortex and any of the stelar tissues which lie outside the portion of the pericycle from which the generating layer is formed.

138. Perennials.—Plants which live for a single year have usually but a small amount of periderm formed, or sometimes none at all. In those, however, which are perennial, periderm is formed not only during the first year's growth, but the activity of the generating layer is resumed at the beginning of succeeding seasons, so that annual additions are made to it. In the cork oak, for example, there is an extraordinary development of cork, which becomes so thick and is so resistant to the passage of water that it serves for the manufacture of stoppers. In the bottle-cork mechanical tissues occur, not in zones, but in isolated patches, forming the gritty masses in poor corks.

139. Secondary periderm.—The dead tissues which accumulate from year to year upon the outside of perennial stems constitute a large part of what is known as the bark. In the bark of most trees one or more generating layers form in addition to the first, giving rise thus to secondary periderm (fig. 129). The secondary periderm may be either concentric with the first, in which case the outer parts of the bark will be made of concentric layers which separate readily from each other; or the new generating layer may intersect the

* The epidermis sometimes continues to grow for many years, while a secondary cortex is formed under it. In this case no sloughing off occurs.

outer one, so as to isolate a mass of tissues of greater or less size. When this mass is killed by the formation of a sheet of cork on its inner face it gradually dries up and ultimately breaks away in the form of a scale or flake (fig. 129). Bark of this sort, such as that of the hickory, sycamore, or apple,

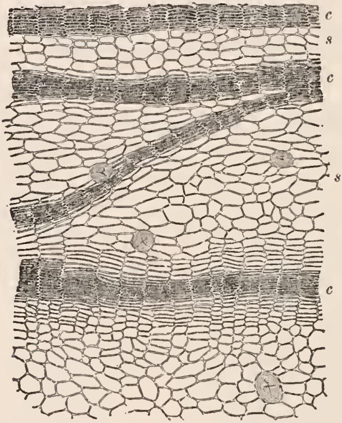


FIG. 129.—Part of a transverse section of the bark of cinchona. *c*, layers of cork formed by a transient cork cambium. *s*, thin-walled tissues, with occasional stone cells. The sheets of cork cells are lines of weakness along which the flakes of bark split off. Magnified 665 diam.—After Warnecke.

is known as scaly bark. In other trees the dead outer portions are persistent, and are only gradually worn away by the action of the weather. Such persistent parts become seamed or deeply furrowed lengthwise by the increased size of the stem within and the constant drying and shrinking of the dead parts. Such bark is called furrowed or ridgy bark.

140. Lenticels.—In stems in which the generating layer of the periderm is formed from the epidermis or the cortex adjacent to it, the cork cells produced show certain modifications at points corresponding to the stomata of the epidermis. Here the cork cells become rounded and loosened from one another (figs. 130, 131). The epidermis under the strain ruptures first at the stoma, and exposes this powdery mass of cells through a usually biconvex rift, whose shape suggested for the structure the name *lenticel.* Lenticels are formed either beneath single stomata, or, when the stomata are not uniformly distributed, beneath the clusters of stomata. When the generating layer of cork is deep-seated the lenticels produced are without relation to the position of the stomata.

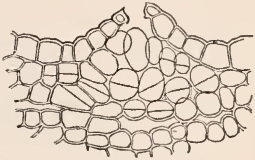


FIG. 130.—A bit of a transverse section of the cortex of elder, showing a very young stage in the formation of a lenticel. The cortical cells under a stoma have divided tangentially and are forming a loose tissue which has already torn apart the guard cells. (See fig. 131.) Magnified 120 diam.—After Stahl.

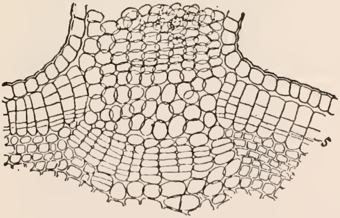


FIG. 131.—Transverse section through a mature lenticel of elder. *s*, the cork cambium. Compare fig. 130. Magnified 80 diam.—After Stahl.

141. 2. The formation of secondary wood and bast.—The position of the internal generating layer (the stelar cambium) is not subject to the same variations as the external

one. In stems of the few monocotyledonous plants which undergo secondary increase in diameter, the internal generating layer arises from the pericycle. Upon division the inner segments, chiefly, differentiate, and from them arise new isolated bundle pairs (in which the xylem bundle surrounds the phloem bundle) and new pith (fig. 132).

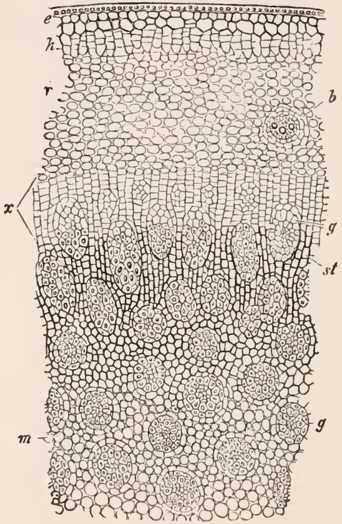


FIG. 132.—Portion of a transverse section of a stem of Dracæna, in process of secondary thickening. *e*, epidermis; *h*, periderm; *r*, cortex, in which a bundle-pair *b* is passing out to a leaf; *x*, stelar cambium; *g*, *g*, vascular bundles; *m*, primary pith; *st*, secondary pith. The amount of secondary thickening is shown by the radial arrangement of cells of secondary pith. Magnified about 50 diam.—After Sachs.

In the many dicotyledons whose stems increase in diameter, the stelar cambium arises between the xylem and the phloem bundles of each pair, and extends across the pith rays which intervene, thus forming a complete zone nearly

concentric with the surface of the stem (figs. 120, 124, 133 *A*). As its cells divide, sometimes their inner, sometimes their outer segments differentiate into the tissues which they then

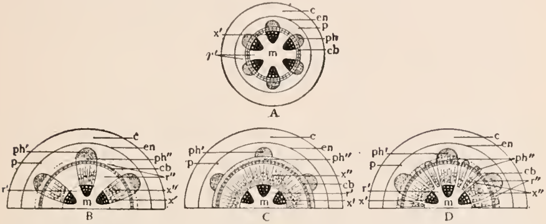


FIG. 133.—Diagrams of transverse sections of stems illustrating modes of secondary thickening. In all *c*, cortex; *en*, endodermis; *p*, pericycle; *ph'*, primary phloem; *ph''*, secondary phloem; *cb*, stelar cambium; *x'*, primary xylem; *x''*, secondary xylem; *r'*, primary pith rays; *r''*, secondary pith rays.—After Van Tieghem.

adjoin. Inside the generating layer between the bundles there arises, therefore, secondary xylem which becomes wood; outside it, secondary phloem, or bast. Each bundle is thus increased in its radial dimension (fig. 124).

142. Pith rays.—The generating layer in the pith rays arises from the pericycle or from some part more deep-seated, but in any case it connects directly with the generating layer between the adjacent bundles (fig. 124). In this portion of the generating layer two distinct modes of development are to be observed: either the tissues produced by the division of the cells differentiate into pith tissue (*B*, fig. 133), or they form secondary wood and bast coresponding to that produced between the adjacent bundles. In the latter case, therefore, a complete zone or ring of secondary wood and bast is formed, so that the pith occupies the center. Upon the ring of secondary wood thus produced the primary wood bundle projects into the pith, and upon the ring of secondary bast the primary bast bundle projects into the cortex (*C*, fig. 133).

Intermediate between these two methods, it is common to have new bundles produced by the differentiation of the secondary tissues formed in the pith rays, these bundles remaining separated by pith rays. In this case a xylem bundle is usually first formed, followed shortly by a phloem bundle outside (*D*, fig. 133).

The secondary bundles thus formed can, of course, have no connection with those which enter the leaves. In this they differ from the primary bundles, branches from which enter each leaf. (See ¶ 163.)

143. Annual rings.—If the stem is perennial, year after year the stelar cambium resumes its growth, adding layer after layer to the secondary wood and bast. Thus most trees have their shaft-like trunks formed. The generating layer forms a line of weakness, especially when dividing rapidly, and the parts outside separate readily from the wood. They constitute the bark.

144. 3. The bark.—As has been already shown, the outer part of the bark consists of the dead, dry, shriveled tissues of the periderm lying outside the cork cambium. The inner portions of the bark are composed of the tissues which lie between the cork cambium and stelar cambium. This inner part contains a greater amount of water than the outer, and always some living tissues. It may consist of a part of the cortex (depending upon the place of origin of the periderm), the pericycle, and the primary and secondary bast. As the tree grows older, the secondary generating layers of the periderm invade the cortex and the bast, until, with weathering, the bark may come to consist wholly of secondary bast. It attains considerable thickness only when the loss from this cause is slow.

CHAPTER X.

THE LEAVES.

145. Primary leaves.—Leaves are distinguishable into primary and secondary. The primary leaves arise directly from the first cells produced by division of the egg. In the fernworts two of the octants into which the egg divides produce the primary leaf. This is entirely unlike the *secondary* leaves, which arise upon the sides of the stem. In seed plants, one, two, or more leaves develop as members of the embryo, only a few plants (and those probably degenerate in this respect) not forming leaves before the embryo enters its resting stage.

The primary leaves of seed plants are called cotyledons (figs. 134, 135). They are usually transient, and not rarely so distorted by acting as storage places for reserve food that they do not function as foliage leaves at all. In extreme cases of this kind they remain in the seed coats when the embryo resumes its growth, as in pea and oak.

146. Secondary leaves are generally numerous and much more conspicuous. It is these which are usually meant by "leaves," unless primary leaves are specially named.

147. Development.—If the apex of the shoot is examined, its progressive differentiation into stem and leaves can be observed. Upon the sides of the growing point swellings of various size appear, the smallest being nearest the apex (fig. 95). These swellings are the fundaments of the leaves, into which they become transformed by further development. Similar swellings appear later just above the leaf fundaments,

which are at first not distinguishable from them, except by position (fig. 96). These become the branches. Both leaf and branch have their origin usually in the outer layers of the shoot, and can only be distinguished by the later course of development. The growth of the branch is commonly indefinite, while that of the leaf is generally limited; the

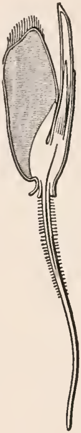


FIG. 134.

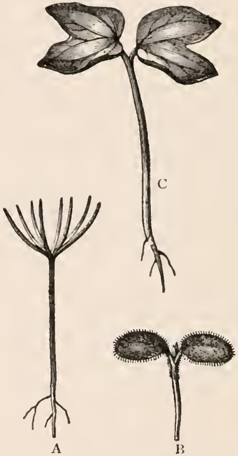


FIG. 135.

FIG. 134.—A seedling of wheat, with grain still attached cut through lengthwise, showing the single primary leaf with its back applied to the store of reserve food in the grain (the shaded part). The first two secondary leaves are also developing, and the primary root has extended. Magnified 4 diam.—After Kerner.

FIG. 135.—Seedlings, showing primary leaves. *A*, a fir (*Abies orientalis*); *B*, the dog-rose; *C*, a morning-glory. Natural size.—After Kerner.

branch usually develops leaves and often buds as lateral outgrowths, while the leaf rarely forms buds normally; the axis of the branch is generally radial, like the parent axis, while the leaf is generally flattened and dorsiventral. In most cases, also, the leaf subtends the branch. Both leaf and branch mark those points of the stem known as the nodes.

148. Arrangement.—Leaves appear in regular succession upon the stem, the youngest being nearest the apex. Their distribution along the sides of the stem, though extremely various, may be reduced to two main types. Either (1) the leaves are formed singly at the nodes, or (2) more than one leaf occurs at each node. When the leaves are single, successive leaves may stand upon exactly opposite sides of the stem, so that the third leaf, counting from below upwards, stands over the first; or the fourth leaf may stand over the first; or the sixth over the first, and so on. A transverse section of a bud shows the mode of arrangement, and a study of such sections makes it evident that each leaf appears in the widest space between the two preceding leaves, i.e., where it encounters the least resistance. That this is the determining factor is shown by the fact that the order of arrangement may be artificially altered by pressure or distortion of the bud. When two or more leaves occur at each node, the members of successive circles ordinarily alternate with each other. This alternation is due to the same cause.

149. Form.—Leaves show a great variety of form and structure. Even upon the same plant leaves of various forms occur. The primary leaves are usually different from the secondary leaves, both in form and size. The most abundant form of secondary leaves is foliage leaves. These may be very simple, as the "needles" of the pines, or differentiated more completely, as in the deciduous trees. The mature form of the complex foliage leaf is frequently not attained until several nodes above the point at which the primary leaves arise; and, if only one or two leaves are produced each season, as in many ferns, the mature form may not appear for several years.

150. Foliage leaves.—A well-developed foliage leaf may usually be divided into two equal parts by a plane passing through its base and the axis of the stem to which it is

attached, i.e., it is bilateral. Moreover, the upper and under surfaces are usually different, i.e., it is dorsiventral. It has three parts, the base, the stalk, the blade (fig. 136). The leaf base is always present, but either the leaf stalk or the leaf blade or both may be absent. The leaf blade is ordinarily winged; indeed it is for this reason that it

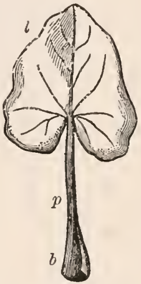


FIG. 136.

FIG. 137.

FIG. 136.—Leaf of *Ranunculus Ficaria*. *b*, leaf base; *p*, petiole, or leaf stalk; *l*, lamina or leaf blade. Natural size.—After Prantl.

FIG. 137.—A leaf of a grass, with part of stem to which it is attached. *s*, sheath (leaf base) attached all around node *k* of the stem *h*, *h*; *f*, blade; *l*, the ligule, an outgrowth from the surface. Natural size.—After Frank.

received the name "blade." Either the stalk or the base or both may also be winged.

151. 1. **The leaf base.**—The leaf base is generally enlarged so as to form a sort of cushion by which it is attached to the stem. When a broad base is attached over a considerable arc of the circumference of the stem, so that it encircles it more or less, the base is said to be sheathing (fig. 136). In grasses, for example, the leaf base is attached over the entire circumference of the stem, and enwraps it completely for a considerable distance above the node (fig. 137).

152. Stipules.—The leaf base frequently branches. These branches, commonly two in number, are called stipules (fig. 138). They vary from slender, awl-shaped bodies to flat-

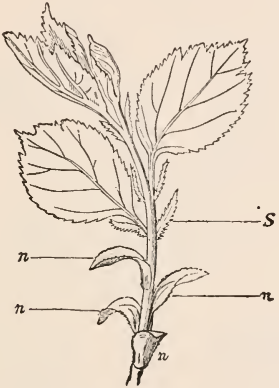


FIG. 138.—A growing shoot of a thorn (*Cratægus punctata*). *n*, leaves developed as bud scales which protected the parts above when in the bud; *S*, stipules. Natural size.—After Reinke.

tened and leaf-like ones. The stipules may remain attached to the base throughout the life of the leaf, or may fall away early. Usually the two are separate, but they may be united with the leaf base itself, forming wings for it, as in roses (fig. 139), or they may be united with one another so as to form a sort of sheath encircling the stem (fig. 140). When the leaf base is winged, the wings extend downward as lobes more or less encircling the stem. In many cases the leaf is said to be clasping (fig. 141). These lobes may even unite on the other side of the stem, so that the stem seems to penetrate the base of the blade. (See fig. 142.) When two leaves occur at the same node, corresponding lobes of the

leaf bases may unite, so that the stem seems to pass through the center of a leaf which extends equally on each side of it. (See fig. 143.)

Fig. 139.—A young flowering shoot of dog-rose, showing various forms of leaves and transition from one to the other. n^1–n^5, scale leaves; l^1–l^3, foliage leaves; h^1–h^3, bracts; the flower leaves not clearly shown. The scale leaf, n^1, shows a leaf base, winged by stipules *b*, with only a trace of stalk and blade *a*. Trace these parts into foliage leaves, where the blade becomes compound, and subsequent reduction through the series of bracts. Natural size.—After Luerssen.

153. 2. **The leaf stalk.**—The leaf stalk is also known as the *petiole*. Its form is more or less cylindrical, usually with a groove or channel upon the upper side. Sometimes the petiole is flattened in a vertical plane, as in aspen poplars.

When this flattening is extensive, so that the petiole becomes thin and leaf-like and the blade is wanting, it functions as a foliage leaf (fig. 144). Not infrequently, the petiole is winged, as in the orange. It may be entirely wanting, in which case the blade arises directly from the base, as in most grasses (fig. 137).

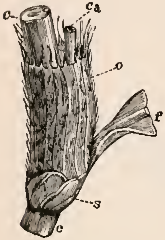


FIG. 140.

FIG. 141.

FIG. 140.—Stipules of *Polygonum* forming a sheath, *o*, above the sheathing leaf base *s*, of the cut-off leaf *f*; *cc*, the stem; *ca*, an axillary shoot. Natural size.—After Frank.

FIG. 141.—Leaf of *Thlaspi* with clasping base. Natural size.—After Prantl.

154. 3. **The leaf blade.**—To this part of the leaf the word "leaf" itself is frequently applied. In general, the leaf blade is so broadly winged as to be thin and flat; but all gradations

FIG. 142.

FIG. 143.

FIG. 142.—Shoot of *Uvularia*, showing perfoliate leaves below. About half natural size.—After Gray.

FIG. 143.—A shoot of wild honeysuckle, showing upper leaves connate-perfoliate. About half natural size.—After Gray.

exist between such forms and those that are much folded or crumpled, thick and fleshy, or even cylindrical.

FIG. 144.—A shoot of *Acacia*, showing at *a* a twice-branched (compound) leaf with roundish petiole; at *b*, a similar leaf with flattened blade-like petiole; at *c*, phyllodia, i.e., blade-like petioles without true blades. About half natural size (?).—After Frank.

If a thin blade be held between the eye and the light, two parts become evident: (1) a green tissue (mesophyll), more or less opaque; and (2) translucent "nerves" or "veins." * The larger of these, usually called the "ribs," * frequently form ridges upon the under surface.†

155. Branching.—The outline of the blade is extremely various. It is dependent upon the character and extent of its branching, which may be either slight or extensive. Slight branching gives rise to teeth of various forms (fig.

* These words must not be thought to indicate any resemblance in function to the same parts in animals, but only similarity of position or appearance.

† For further account of structure see ¶ 168.

145). More profound branching is evident in divided or parted leaves (fig. 146). In some blades the branching is so extensive and complete

Fig. 145.

Fig. 146.

Fig. 145.—Diagrams of slight leaf branching. *A*, leaf with crenate edge; *B*, leaf with dentate edge; *C*, leaf with serrate edge.—After Bessey.

Fig. 146.—Leaf of *Amorphophallus*, showing sympodial branching. The successive lateral axes are numbered in order. The extent of branching makes the blade divided. Reduced.—After Sachs.

that the green tissue no longer fills the intervals between the larger ribs, but the blade is made up of a series of independent portions united to a common stalk. Each ultimate branch of the blade is known as a *leaflet*. Blades in which the green tissue is continuous, even though deeply divided, are called *simple* leaves. (See figs. 136, 138, 141, 142, 145, 146.) Those which are segmented into leaflets are called *compound* leaves. (See figs. 139, 144, 147, 148, 149.)

156. Venation.—The mode of branching of the blade is indicated by the main ribs which occupy the axes of growth. (See ¶ 169.) Study of distribution of the ribs and veins of the blade, that is, of its *venation* or *nervation*, shows that monopodial branching (¶ 93) is the common mode, sympodial branching occurring rarely (fig. 146). The arrangement of the larger ribs may be reduced to two main types.* (1)

* Compare mode of branching of shoot, ¶ 103.

There may be a main rib, from whose flanks arise at regular intervals a series of lateral branches which may themselves

FIG. 147.

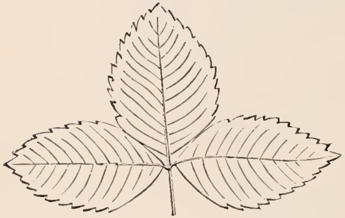


FIG. 148.

FIG. 149.

FIG. 147.—A palmately branched (compound) leaf of horse chestnut. About one-fifth natural size.—After Bessey.
FIG. 148.—A palmately branched (compound) leaf.—After Bessey.
FIG. 149.—Leaflets of maidenhair fern showing dichotomous branching of veinlets, which end free. Natural size.—After Ettingshausen.

again be branched in various ways. Such a leaf is said to be *pinnately veined* (figs. 138, 151, 153). Or (2) from the top of the petiole several large ribs of almost equal strength may be given off. Such venation is *palmate* (figs. 150, 152). These may be parallel (fig. 150) or radiate (fig. 152).

The distribution of the small veins or nerves shows three types. They may either (1) connect with each other so as to form an irregular meshed network (fig. 151); or, (2) leaving a rib nearly at right angles, they may run parallel with each other to join another large vein; or (3) they may leave

the large vein and end free (fig. 149). In the first type the finest branches of the veins, too delicate to be seen without the microscope, often end free in the meshes formed by the next larger branches (fig. 164). Near the margin of a blade

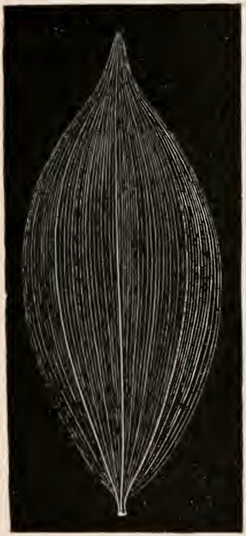


FIG. 150.

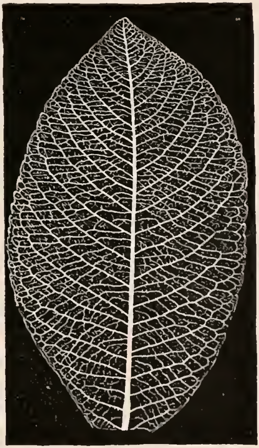


FIG. 151.

FIG. 150.—Parallel venation of leaf of *Polygonatum latifolium*. Natural size.—After Ettingshausen.

FIG. 151.—Pinnately netted venation of leaf of a willow. Natural size.—After Ettingshausen.

the larger veins are often so connected with each other as to form one or more series of arches whose convex side is directed toward the margin. These form a sort of selvedge and protect the leaf against tearing (fig. 153).

157. Special forms.—Foliage leaves may be modified to serve special purposes without wholly losing their function as

FIG. 152.—Palmately veined and branched leaf of Norway maple. About half natural size.—After Kerner.

foliage. For example, the petiole may be made sensitive to contact and adapted to wrap about slender objects, like a tendril, as in clematis and nasturtium (fig. 154). Such plants are called leaf-climbers.

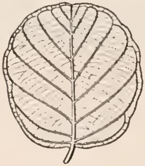


FIG. 153.

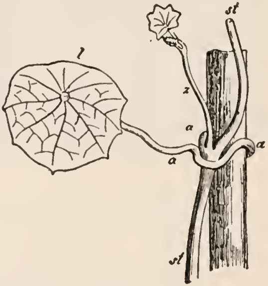


FIG. 154.

FIG. 153.—Pinnately veined leaf of buckthorn, with looped ribs forming a selvedge.—After Kerner.

FIG. 154.—Portion of a plant of the dwarf garden-nasturtium (*Tropæolum minus*). The long petiole *a*, *a*, *a* of the leaf *l* is sensitive to contact and has coiled about the support and its own stem, *st*. *z*, axillary branch. Natural size.—After Sachs.

Some plants develop their leaves into the form of sacs or pitchers. These ordinarily represent the blade of the leaf, and are more or less urn- or trumpet-shaped. They may be either without petiole, as in Sarracenia (fig. 155); or

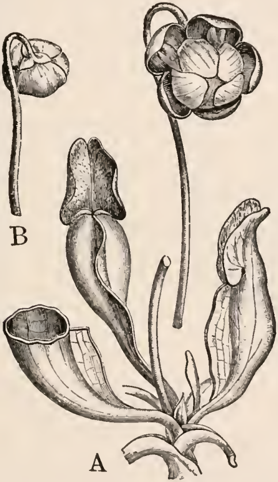


FIG. 155.—Pitcher-plant (*Sarracenia purpurea*). Leaf above *A* cut off to show trumpet form. One-third natural size.—After Gray.

petioled, as in Utricularia (figs. 383, 384); or the petiole may be winged to serve for foliage, as in Nepenthes (fig. 382). A few plants have their leaves modified so as to serve as traps, which, by their sudden movements, capture small animals (figs. 386, 387, 388).

But generally the foliage function is subordinated to the other work, and the leaf takes on peculiar forms, the more important of which are as follows:

158. (1) **Tendrils.**—The leaf blade alone, or some of its branches, or the petiole and blade, may develop as a cylindrical body, without wings and sensitive, known as a tendril. In the pea, the stipules become very large, and take the function of the reduced blade (fig. 156). In other plants the base may be broadly winged for the same purpose.

Fig. 156.

Fig. 157.

Fig. 156.—Portion of shoot of pea, with a pinnately compound leaf whose upper leaflets are modified into tendrils and the stipules greatly developed to serve as foliage. About half natural size.—After Frank.

Fig. 157.—Piece of the stem of locust (*Robinia Pseudacacia*), showing stipules in the form of thorns. Natural size.—After Kerner.

159. (2) **Thorns.**—The leaves may develop into slender conical and sharp-pointed thorns or spines, either branched or unbranched (fig. 390). Sometimes the stipules alone become thorns, as in locust and acacia (fig. 157). Neither tendrils nor thorns can be distinguished structurally from similar forms of the shoot.

160. (3) **Scales.**—In buds, on underground stems and on various parts of the aerial stem, are found small, scale-like leaves of various shapes (figs. 101, 102, 105, 109, 138, 139,

358). These scales may represent the sheathing base only; they may be the base with the stipules (fig. 139); or they may represent the leaf base and the blade. The petiole in all cases is wanting. In addition to the modification of form, scales, especially those that are protective, have their tissues firmer and more resistant to cold and unfavorable external conditions. Not infrequently the scales are covered with secreting hairs, or possess glands sunk beneath their surfaces, whose function is to produce and excrete resins and similar materials. The inner protective scales of buds (fig. 98) are often covered with an abundant coating of woolly hairs, which serve to prevent rapid change of temperature in the interior of the bud.

161. (4) **Flower leaves and bracts.**—On certain parts of the stem, leaves are commonly profoundly modified to carry the spore cases. They are called sporophylls (*c*, *st*, fig. 104). (See ¶ 329.) Adjacent to these are others which may be highly colored and adapted in form to protect the sporophylls, and to facilitate the visits of insects (*s*, *p*, fig. 104). A shoot whose leaves are thus clustered and specialized constitutes a "flower." The leaves adjacent to the flower leaves are also more or less modified in form and reduced in size. They are called *bracts* ($h^{1, 2, 3}$, fig. 139). (See also ¶ 359.)

162. (5) **Storage leaves.**—Other leaves are utilized for purposes of storage. For this purpose the ribs are reduced in number and size, while the softer tissues of the leaf are often enormously developed, and serve as the receptacles of the reserve food. The primary leaves of the seed plants (cotyledons) are often much distorted by the deposit in them of reserve food for the embryo. When such leaves possess sheathing bases the structure resulting from the union of a number of such leaves upon a short axis is called a bulb. (See also ¶ 109.) The leaves of buds are sometimes thickened by the deposit of food material, and when such buds

loosen from the plant they may produce a new plant, as in the tiger-lily (see ¶ 361–364). Both base and blade may be used for storage, as in the century-plant; or the entire leaf may serve the same purpose, as in the cultivated cabbage.

163. Structure.—Three regions in each part may be distinguished, as in the root and stem: (1) the epidermis; (2) the cortex; both continuous with that of the stem; (3) the steles, continuous with those of the stem when the latter contains several steles, or branches of it when the stem contains a single stele.

164. (a) The petiole.—The structure of the petiole agrees in all essentials with that of the stem (see ¶ 124 ff.). The epidermis forms the outer surface, frequently with hairs or emergences (see ¶ 128, 129). The cortex consists of rounded or cylindrical thin-walled cells, the outer layers containing chlorophyll, and frequently with angles much thickened for strength. Mechanical tissues forming strands or bands are also frequently present in the cortex. In water plants, e.g., in water-lilies, large intercellular chambers, often forming extensive canals, are present. There may be a single stele, surrounded by an endodermis and containing several or many vascular bundles (*B*, fig. 158); or there may

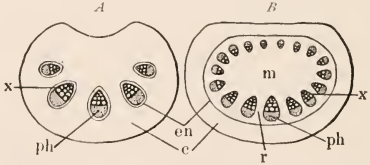


FIG. 158.—Diagrams of transverse sections of petioles showing two most common structures. *A*, petiole with several steles. *B*, petiole with one stele, containing a number of bundle pairs. *c*, cortex; *en*, endodermis; *ph*, phloem; *x*, xylem; *m*, pith; *r*, pith rays The letters *A*, *B* stand on the upper or ventral side of petiole. —After Van Tieghem.

be several steles, each surrounded by a special endodermis and consisting of little more than a pair of vascular bundles

(*A*, fig. 158). In transverse section the vascular bundles are variously placed, being irregularly scattered, or disposed in one or several groups. The single group is most common, with the paired bundles placed so as to form a crescent, or even a complete ring, which is flattened above or triangular. The largest pair is generally median and dorsal (fig. 158), with smaller ones right and left.

165. (b) The blade.—In broad leaves, the epidermis of the blade is made up of tabular cells, often with wavy lateral walls (fig. 159). In narrow leaves the epidermal cells are

FIG. 159.—Surface view of epidermis from under side of leaf of bracken fern (*Pteris*), showing wavy cells, except over veins, *v*, where they are elongated. *st*, stomata. The dot in each cell represents the nucleus. Highly magnified.—After Sedgwick and Wilson.

longer than wide (fig. 160). Over the veins the cells are elongated parallel with the vein. The epidermal cells are generally free from chloroplasts. The epidermis usually consists of one layer, but in some plants becomes several-layered, either to serve as additional protection against evaporation or for use as a water-storing tissue. (See ¶ 441.)

Hairs of many sorts, plain, stinging and glandular, and of various sizes, arise from the epidermis (figs. 361–365). They are essentially like similar structures on the stem (figs. 113, 114).

166. Stomata.—Numerous intercellular spaces bounded by a pair of specialized cells, called guard cells, penetrate

FIG. 160.

FIG. 161.

FIG. 162.

FIG. 160.—Surface view of epidermis from the leaf of oat, showing elongated cells (more elongated over vein, *n*, *n*) and stomata arranged in lines. Moderately magnified.—After Frank.

FIG. 161.—Perspective view of a stoma from the under epidermis of the beet leaf, showing the sloping sides of the slit, the crescentic guard cells with chloroplasts. Highly magnified.—After Frank.

FIG. 162.—Sections through stomata of beet at right angles to their length. The upper figure shows the stoma open; the lower closed. The black line represents the primary wall, to which additional material, especially in the guard cells, has been added. These thickenings serve by their elasticity to close the stoma. Opening is due to turgor of the guard cells. The chloroplasts and granular protoplasm are shown. Highly magnified.—After Frank.

the epidermis. The whole apparatus is called a *stoma* (*st*, fig. 159, 160). The guard cells are crescentic, sometimes with enlarged ends (fig. 160, like curved dumb-bells then),

and are sensitive to various external conditions, especially light, so as to control the size of the slit-like space between them by changes in their curvature (fig. 162). This slit is formed, like most intercellular spaces, by the partial splitting apart of the cells. It communicates with extensive intercellular spaces in the interior.

The stomata are very numerous. In different plants, in the space here enclosed [1 sq. cm.], the numbers usually vary from 4000 to 30,000, sometimes, however, reaching as much as 60,000 to 70,000 in the olive and rape. They are not equally distributed on the two sides of the leaf, being usually more numerous on the under side, where there are more internal intercellular spaces. They may be wanting on the upper side, as in lilac, begonias, and oleander. There are no stomata on submerged leaves nor on the under sides of floating leaves. In some plants they are found in clusters, in others uniformly distributed.

167. Cortex.—The cortex of leaves is called the mesophyll. It consists of thin-walled, active cells, for the most part richly supplied with chloroplasts. In thick leaves the internal cells are without them. In some leaves the cells of the mesophyll are nearly uniform, but in most those near the upper surface are more elongated and close set, forming one or two rows, with their ends outward, while cells near the lower surface are irregular in form, with large intercellular spaces. These tissues are known as the palisade and spongy parenchyma (fig. 163).

About the steles, the cortex forms the usual endodermis (*gs*, fig. 163), and often develops along the larger into one or two strands or a sheath of mechanical tissues. These tissues, together with a stele, constitute the rib or vein, often so massive as to project beyond the other parts in thin leaves.

168. Steles.—The steles are numerous and ramify through the blade. Their structure is essentially as described for the

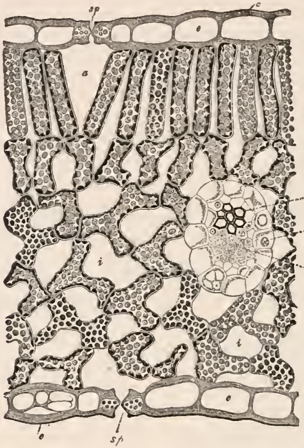


FIG. 163.—Diagrammatic vertical section of a leaf. *e*, *e*, epidermis, with cuticle *c*, *c*, and stomata *sp*, *sp*. Between upper and lower epidermis lies the mesophyll, with cells abundantly supplied with chloroplasts. The upper row of elongated cells is the palisade parenchyma; the rest form the spongy parenchyma, both with many intercellular spaces *a*, *i*, *i*, communicating with outside air through stomata. In the mesophyll lies a small vein, here cut across, composed of a ventral xylem bundle *g*, a dorsal phloem bundle *s*, surrounded by the endodermis *gs*, and the pericycle (between *g* and *gs*).—After Sachs.

stem (¶ 127). Each of the smaller consists of little more than a single pair of vascular bundles. The xylem bundles alone form the last branches (fig. 164), the phloem disappearing earlier. The larger ribs may form one or two strands or a complete sheath of mechanical tissues by the development of the pericycle, and the bundles proper may be increased by the development of secondary wood and bast. (See ¶ 141.)

169. Growth.—The growth of the leaf is at first apical. In fern-worts its tissues are produced by the continued divi-

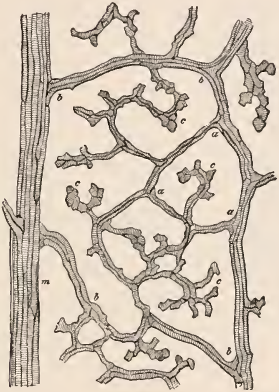


FIG. 164.—A few meshes of the finest veins of a leaf of *Anthyllis*. *m*, main vein; *b*, *b*, branches; *a*, *a*, *a*, a closed mesh; *c*, ends of the finest veins within the mesh. The drawing shows only the xylem bundles; the phloem bundles accompanying them and the mesophyll cells filling the meshes are not shown. Moderately magnified.—After Sachs.

sion of a single apical cell, and the further division of each of the segments so produced (*l*, fig. 76). The branches of such leaves, therefore, arise in acropetal succession. In most seed plants, instead of a single apical cell, there is a cluster of such cells. Growth at the apex often ceases early, and is replaced by growth throughout the whole extent of the leaf. This intercalary growth is sometimes localized between the fundament of leaf base and blade, producing the petiole when one is formed. In elongated leaves without distinct petiole, as in grasses and many other monocotyledons, a zone of growth occupies the entire base of the blade. By the division of these cells, chiefly at right angles to the length

of the blade, its tissues are produced. In such plants apical growth ceases so early that it can be observed only in the youngest stages.

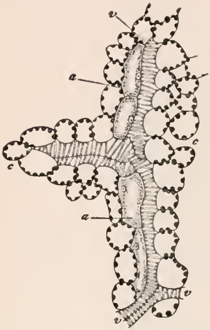


FIG. 165.—Ending of a vein in the mesophyll of a leaf. *v*, *v*, *v*, the spirally thickened cells of the xylem; *c*, *c*, mesophyll cells with chloroplasts; *a*, *a*, cells of the endodermis. Magnified 230 diam. —After Frank.

170. Of branched leaves.—When the leaf is to become much branched, two or more new growing-points develop, so that each of the branches has at its apex a growing-point (fig. 166). These growing-points may arise from the apical growing-point, or from the basal one, or sometimes from both. The branches will appear accordingly in acropetal or basipetal succession, or even in both as they do in the leaves of yarrow. The limits of the growing-point are even more indefinite than in the stem. The cells of which the leaf is composed are produced very rapidly, and at a very early stage division ceases.

171. Wintering.—In those plants which live from year to year, producing new leaves each spring, the unfolding of these from the winter buds is due chiefly to the enlargement of cells already formed. New leaves are ordinarily produced before the close of the growing season preceding that in which they are expanded, and are protected in the winter buds. The partly developed leaves in the bud may be flat, but broad leaves are commonly folded or rolled in various ways.

172. Growth limited.—The growth of the leaves is ordinarily limited, rarely extending over a single season. In a few ferns and coniferous plants the leaves continue to grow for a longer time. Indeed, in the curious Welwitschia (fig. 167),

the basal growth of a single pair of persistent secondary leaves is continued throughout the long life of the plant, while the tips die and are frayed out.

173. Production of the other members.—Leaves give rise under certain conditions to roots or to shoots. The number of plants, however, in which this occurs is comparatively

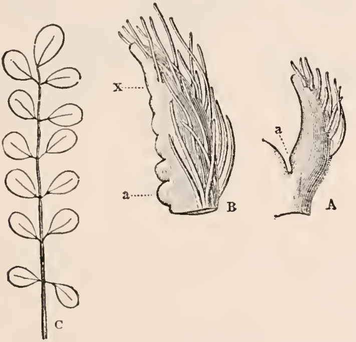


FIG. 166.—Development of the pinnately compound leaf of the locust (*Robinia Pseud-acacia*). *A*, young stage, showing on one flank the first lateral growing-point *a*, which is to produce the lowest leaflet. *B*, an older stage with the fifth growing-point *x* just showing. A sixth is still to be developed. The hairs in *A* and *B* are on the back (under side) of the leaf, and drop off early. *C*, nearly mature leaf. *A*, *B*, magnified; *c*, about ½ natural size.—After Frank.

limited. Roots arise from leaves in precisely the same way as lateral roots arise from stems (¶ 95), that is, they are endogenous in their origin, and develop always near the surface of the steles.

When a leaf produces a shoot, it is from the epidermis or from the green tissue underlying it, never from the steles. Shoots thus arise from the part of the leaf corresponding to that from which branches arise upon the parent shoot.

174. Secondary changes.—Leaves, like stems and roots, undergo certain secondary changes, but these are neither so

common nor so extensive as in the other two members. The formation of several to many layers of cork cells upon the surface of scale leaves is not uncommon. Occasionally similar layers of cork are formed upon the petioles of ordinary

FIG. 167.—*Welwitschia mirabilis*, a coniferous plant of Africa, showing two leaves which grow at base and continue to develop throughout the many years which the plant lives. The tips are dead, and become worn and frayed by winds. $\frac{1}{25}$ natural size.—After Hooker.

foliage leaves. In some cases the large vascular bundles occupying the main ribs undergo changes similar to those described for the bundles of the stem (¶ 141), by which secondary wood and bast are produced.

175. Leaf fall.—One of the secondary changes of most importance is the preparation for the fall of the leaf. This is made by the formation of a layer of secondary meristem across the leaf base at or near the point where it joins the stem. The cells at this point, with the exception of those constituting the vascular bundles, begin a series of divisions at right angles to the axis. A transverse plate of cells is thus formed, some of which cells may become transformed into cork, making a line of weakness; or, without such alteration, the cells may round themselves off by loosening along a definite line, so that the leaf is held only by the steles. The access

of water to this crevice, and its freezing, serve to rupture the remaining tissues, and thus allow the leaf to fall by its own weight, or to be torn off by the wind.

The scar left by the fall of the leaf is protected either by the cork already produced, or by mere drying of the exposed tissues. The leaflets of compound leaves fall in like manner. Sometimes provision for the leaf fall is begun as early as June, as in the Kentucky coffee-tree. In other plants provision for leaf-fall is begun late in the season, and in some, such as the oaks, it is very imperfect, so that the leaves are finally wrenched off by winter storms, or pushed off in the spring by the developing buds beneath them.

PART II: PHYSIOLOGY.

CHAPTER XI.

INTRODUCTION.

176. Division of labor.—The study of the external form and internal structure of plants may be carried on as well upon dead as upon living material. Even the observation of the various stages of development requires only the examination of the plant as it exists at a particular moment. But the plant may also be studied as a working organism. For this purpose living material is indispensable. The work which plants do and by which they are distinguished from non-living bodies is extremely varied, and the more complex the plant the more varied it is. In the preceding part the aim has been to show that there exists great variety of form, and that from the smaller to the larger plants there is gradually increasing complexity by differentiation into tissues and members.

Nutrition, respiration, growth, movement, and reproduction are all executed by the single cell of the simplest plant. But with specialization in structure there occurs division of labor. Each kind of physiological work is known as a *function*, and each part of the organism which does a particular work is called an *organ*.

177. Physiology and ecology.—Physiology proper treats of the plant at work, discussing the different functions and

the way in which these are affected by external forces. In its broadest sense it also treats of the relation of the plant as a whole to external forces and to other living beings, both plants and animals. But it is convenient to separate the latter from physiology proper as *ecology*.* (See Part IV.)

The study of physiology proper necessitates methods of controlling these external forces, carefully planned and repeated experiments, and cautious inferences.

The study of ecology requires observation in the field of the adaptations of plants to prevent injury by unfavorable physical conditions and the attacks of other beings, and to take advantage of the favorable forces and beneficent agents.

178. Chemical and physical forces.—The functions of a plant may be divided for the sake of convenience into nutrition, respiration, growth, movement, and reproduction. These are largely special modes of chemical and physical action. Nutrition and respiration, for example, consist chiefly of a series of chemical changes; while movement is mainly a result of physical alterations in certain organs. But the action of chemical and physical forces does not suffice at present to explain all the phenomena of the living plant. Moreover, the peculiar manifestation of these forces which we call life occurs only in connection with the substance which we call protoplasm.

179. The unit of function.—The functions performed by the entire plant are necessarily a sum of the functions performed by the physiological units of which it is composed. As the unit of structure is the plant cell, so the unit of function is the protoplasmic body of that cell. Although only a portion of any plant is composed of living matter, it is to that living matter only that we are to look for the seat of its powers.

* Spelled in lexicons, œcology, but best usage drops the *o*; sometimes improperly called biology or plant biology.

180. The fundamental powers of protoplasm are four ; it is metabolic, irritable, contractile, and reproductive.

181. Metabolism.—Protoplasm is *metabolic*, that is, it is capable of initiating a series of chemical changes in itself and in substances which come directly under its influence. These changes are of two kinds. They may be *constructive*, i.e., they may build up complex substances out of simpler ones, and so fit them for use in repairing the waste caused by the activity of the protoplasm ; or they may be *destructive*, i.e., they may break down complex substances into simpler, so setting free the energy necessary for the work of the protoplasm. The substances broken down may be repaired in whole or in part, i.e., may take part in constructive metabolism. Those in which no repair occurs often undergo further destructive changes by which they become converted into materials useless to the plant, and to be gotten rid of. Metabolism, therefore, includes all the chemical changes by which food is either manufactured or utilized, and by which waste materials are produced and eliminated.

182. Irritability.—Protoplasm is *irritable*, that is, it exists in such a state that it is sensitive to external influences, which thereby affect the various functions of the whole organism. By reason of its irritability, it may even transmit the effects of an external stimulus from one part to a distant part. Moreover, it is capable of initiating similar changes without the action of any observable external influences, and is, therefore, not only irritable but *automatic*.

183. Contractility.—Protoplasm is *contractile*, that is, it has the power of altering its form, of shortening in one direction and elongating in another, by virtue of inherent forces whose action is not understood.

184. Reproduction.—Protoplasm is *reproductive*, that is, it is capable of so directing the chemical and physical forces

inherent in it that a new organism similar to that of which it forms part may be produced.

185. Adaptation.—The interrelation of these powers, their harmonious coworking and their variation to suit the varying conditions of the surrounding media (air, water, soil, etc.), result in the proper performance of all the functions of the plant. By means of these powers it is brought into relation to the world about it, being adapted to other organisms in whose company it lives, and enabled to withstand the adverse conditions by which it is frequently threatened. Every organism, indeed, must adjust itself first to the external physical conditions, and, second, to other organisms. (See Part IV.)

186. Physical conditions set limits upon the discharge of its functions. Varying amounts of light, of heat, of moisture, determine more or less rigidly how rapidly, or to what extent, each function may be discharged. Every function of the plant is adapted, therefore, to an upper limit, the *maximum*, and to a lower limit, the *minimum*, above or below which the performance of the function in question is impossible. Between these limits there lies some point at which it proceeds most rapidly and effectively. This point is known as the *optimum*.

CHAPTER XII.

THE MAINTENANCE OF BODILY FORM.

Every plant is capable of attaining and maintaining a specific form, which is not permanently altered by the direct action of external forces, and is dependent upon the nature of the plant itself.

187. Naked cells.—If the plant consists of a single mass of naked protoplasm, it may assume a spherical or ovoid shape (fig. 168). In attaining this form the physical forces

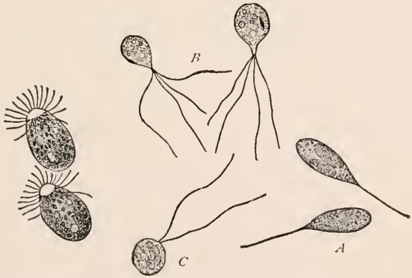


Fig. 168. Zoospores of various forms, swimming in water by means of one or more cilia. *A*, *Botrydium*; *B*, *Draparnaldia*; *C*, *Coleochæte*; *D*, *Œdogonium*. Highly magnified.—After Kerner.

constituting surface tension play a part, but the form is determined chiefly by internal forces inherent in the protoplasm. This is particularly well shown when such organisms extend delicate protoplasmic threads, the cilia, and maintain these

in active motion (fig. 168), or when they extend a portion of the body as a pseudopodium (fig. 169).

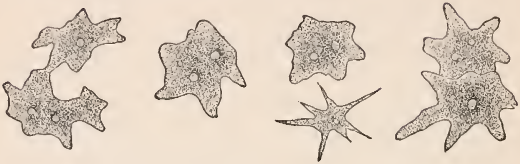


FIG. 169.—Plasmodia, creeping bits of naked protoplasm, showing varied shapes as parts are protruded or withdrawn. Highly magnified.—After Kerner.

188. Turgor.—If the organism be one surrounded by a cell-wall, or if it be made up of a number of cells united, the cell-wall itself plays a considerable part in maintaining the form. This is due to the condition of the cell known as turgor. When fully mature the cell-wall of each active cell is lined by a more or less thick layer of living protoplasm. In the interior of the protoplasm there exist one or more water chambers, the vacuoles (¶ 5). If such a cell as this be measured in its normal condition, and then surrounded for a few moments by a 10 per cent. solution of common salt, re-examination will show that the vacuoles have been diminished, the protoplasm shrunken away from the wall, and remeasurement will show that the cell has diminished both in length and diameter. In its normal condition, therefore, the wall was stretched by the pressure of the contents within. If a cell which has been thus shrunken by immersion in a solution of salt be again placed in water, it may regain, in the course of a few hours, its original condition, that is, it may again become turgid. This would be brought about by the entrance of water into the vacuoles to replace that withdrawn when the cell was placed in the solution of salt.

If a thin piece of rubber tubing be connected with a pump and filled with water until it is stretched, it increases its

diameter and length slightly, and gains, at the same time, a condition of rigidity greater than in its unstretched condition. In a similar way turgid cells are more rigid than those which are flaccid. The union of turgid cells produces a member more rigid than one in which the cells are not turgid. An illustration of this is to be seen in the condition of a wilted, as compared with a fresh, leaf. The turgor of thin-walled cells may play an important part in maintaining the form and position of the parts of a plant.

189. Tissue tensions.—But turgor can affect only those cells whose walls are thin and extensible. Those whose walls have become thick and rigid are not stretched by this force. In the larger plants, however, where both thick-walled and thin-walled tissues exist, it is possible that a mass of thin-walled cells may, by the united tension of its component cells, stretch those tissues which are not themselves turgid. Such strains in the younger regions, particularly, play an important rôle in maintaining the form of these parts. But the tensions in the older parts are generally due to the unequal growth of different tissues. (See ¶ 259.)

190. Mechanical rigidity.—The rigidity of the cell-wall itself must be relied upon by all the larger plants. Certain tissues are specialized by having their cell-walls greatly thickened, and such tissue regions constitute a sort of framework or skeleton, which is filled out by the more delicate tissues. These mechanical tissues are so distributed within the body as to afford frequently the maximum resistance to bending and breaking strains. In the accompanying diagrams the position of the mechanical tissues is indicated in transverse sections of a number of different stems (fig. 170). It will be seen that they illustrate well-known mechanical principles in their distribution. The hollow column (*E*) and the I-beam (*A*, *B*, *C*), two of the most rigid mechanical constructions, are frequently imitated in plants.

In stems of trees rigidity is secured not by the distribution of the mechanical tissues, but by their massiveness. In them the chief mechanical tissues belong to the wood, which forms

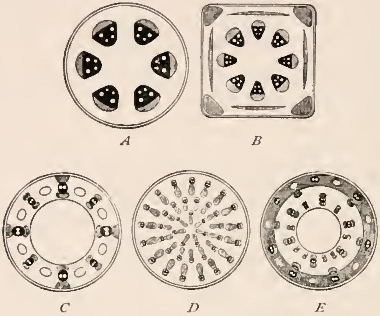


FIG. 170.—Diagrams showing the arrangement of mechanical tissues and vascular bundles in the cross-section of various stems. The mechanical tissue is gray; the vascular bundles black, with white dots. *A*, linden (young); *B*, a mint; *C*, a sedge; *D*, a bamboo; *E*, a grass.—After Kerner.

a solid column occupying the center of the body. Those plants which are supported by the medium in which they live, such as the aquatic plants, are usually without mechanical tissues.

CHAPTER XIII.

NUTRITION.

191. Repair and growth.—Since the body of every plant is constantly wasting away by reason of its own activity, it is necessary that it should be as constantly repaired. It must also, for a considerable time or throughout its whole life, be furnished with material which can be used in the making of new parts. Without an adequate supply of food, therefore, neither repair nor growth is possible. To understand what materials are necessary for repairing waste and forming new parts of the living plant, the constituents of a plant may be determined by chemical analysis.

192. Chemical composition.—The greater portion of the weight of every plant is found to be water. Of the firmer parts it forms as much as 50 per cent., while of the softer parts it may form 75 or even 90 per cent. The most watery portions of some plant bodies, such as the juicy portions of fruits and the whole body of the algæ, may contain only 2 to 5 per cent. of solid matter. The solid material, left after driving off the water at a temperature of 110° C., is found to consist chiefly of three elements, carbon, hydrogen, and oxygen. The most abundant element in addition to these is nitrogen. If the dry substance be burned these four elements are driven off in gaseous forms, and there remains a white material which crumbles under pressure, the ash. An analysis of the ash reveals the presence of sulfur and phosphorus in considerable amounts, and also smaller quantities of the following elements: calcium, magnesium, potassium, iron,

sodium, chlorine, and silicon. Of these seven, the first four are found in the ash of all plants, and the remaining three are very common. In addition to the elements enumerated, about 25 others are known to occur in the ash of plants, but only in minute quantities.

A. The water in the plant.

193. Necessity.—Since water forms such a large percentage of the weight of fresh plants, it is manifest that it must be supplied in relatively large quantities, if the plant is to continue in an active condition. A portion of this water may be used up in the chemical changes occurring in the body, but it is not possible to discriminate between this and the water which is necessary to furnish the proper physical conditions of life. Water is the great solvent by which materials of various kinds are carried into the plant body, and by which a still greater variety within it are transported from place to place. Before discussing the food of plants, therefore, the relation of water to the plant may be examined.

194. Air, water, and land plants.—Some plants are not in contact with water except at irregular intervals. These are called air plants, and include some algæ, liverworts, mosses, fernworts, and seed plants. All these, however, are able to live only in an atmosphere containing large quantities of water vapor, or in those regions where they are frequently sprayed with water. Water plants float upon the water, or are submerged in it. As distinguished from both air and water plants, are those which normally have the root system and sometimes a portion of the stem buried in the soil, continually or intermittently in contact with liquid water, while the shoot system is occasionally sprayed by rain. Such may be called land plants.

195. Solutions in water.—In no case, however, is the water in which plants are immersed, or with which they

are sprayed, pure water. It always holds in solution substances derived from the atmosphere or from the soil with which it has come in contact. These substances are either organic or inorganic, and they enter the plant, along with the water, through those organs which are adapted to absorption.

196. Absorption of water.—In air plants of the simpler sorts, any parts exposed to the moist air or rain can absorb water. In liverworts and mosses the thallus or the leaves are active absorbents. In the higher plants, such as the aerial orchids, the external cortex of the roots is especially adapted to absorb liquid water, or to condense the water vapor of the atmosphere.* In water plants the surfaces which are normally in contact with the water are absorbing surfaces. Such plants may be either wholly without a root system, or it may be only sufficiently developed to anchor them in the mud. In land plants the root system is especially adapted to the absorption of water. Only minute quantities of water are absorbed by the leaves and other aerial parts. The revival of a wilted plant by spraying seems to be due more largely to checking the loss of water by evaporation than to the slight absorption which may occur. The root system of the land plants is developed in contact with the soil.

197. Soil.—The soil consists primarily of finely divided particles of rock, whose nature and size determine the qualities by which soils are ordinarily distinguished into gravelly, sandy, loamy, clayey, etc. Mixed with these rock particles is more or less organic material derived from the offal of plants or animals. When decaying plant offal predominates, the soil is known as vegetable mold or humus, which naturally forms the upper layer of the soil of forests. To garden or field soils, not naturally rich in organic matter, this is

* If such condensation really occurs (as is generally alleged), it does not suffice to keep the plants supplied with the required amount of water.

frequently added artificially. Both manures and artificial fertilizers (the latter consisting usually of dried and ground animal offal) are added chiefly for the purpose of supplying compounds of nitrogen and phosphorus.

198. Soil water.—No matter how fine the soil may be, the rock particles are not in close contact, but, on account of their angular outline, leave spaces of greater or less size to be occupied by other materials. If a soil be examined immediately after a heavy rain-fall, these spaces will be found completely occupied by rain-water. If the soil be so situated as

FIG. 171.—Diagram of a portion of soil penetrated by root hairs, h, h', arising from root, e. At z, s, s' the hair has grown into contact with some of the soil particles, T, which are surrounded by water films (shaded by parallel lines), β, α, τ. The white spaces are air bubbles, δ, δ', γ, γ'. When water enters the hair at α, the thickness of the film α, β, τ will be diminished, and some water will flow towards this point, reducing all the other water films in the vicinity. More air enters from above. When rain falls, the reverse process occurs; the films thicken, and the air may be entirely driven out, to return as the surplus water drains away.—After Sachs.

to be naturally drained, considerable quantities of this water will disappear gradually, and the larger spaces between the soil particles will be occupied partly by films of water adherent to the soil grains, and partly by bubbles of air (fig. 171).

199. Salts dissolved.—The water which thus filters through the soil dissolves and retains certain of its constituents. As the rain passes through the atmosphere it also dis-

solves certain substances found therein, notably minute quantities of ammonia and nitrous acid. By this means compounds containing nitrogen are constantly being brought to the soil by the rain.

200. Root absorption.—The structure of the root system has been explained (¶ 78–82). The root hairs come into close contact with the soil particles, pushing them aside somewhat, and being in turn more or less deformed by their resistance (*z*, *s*, fig. 171). So close does the contact of the root hairs and soil grains become that many particles of the soil are imbedded in the walls of the root hairs (fig. 84). The root hairs are not only in contact with the soil particles, but also with the films of water, which occupy the spaces between them (*a*, fig. 171). They are thus in a position for absorbing water from the adjacent films.

201. Limit of absorption.—Not only is the water immediately in contact with the root a source of supply, but even that in the deeper and more distant parts of the soil. For when, by the entrance of some water into the root hair, the thickness of that layer has been decreased, the disturbance of equilibrium causes a flow from neighboring layers to equalize again the surface tensions. This goes on until the films of water upon the soil grains become so thin that the water particles are held too tenaciously to be pulled away by the root. There remains in such exhausted soil, which seems dry as dust to the touch, 2 to 12 per cent of water unavailable for the plant.

202. Solvent action.—The root hairs also exert a slightly solvent action upon the soil particles themselves by reason of the carbonic acid and the acid salts which they excrete. By this means various minerals, especially carbonates of lime and magnesia (limestone), which could not be dissolved by the water alone, may be brought into solution.

Water enters the root hairs by the physical process known

as osmosis, the protoplasm, braced by the cell-wall, acting as the membrane, and the cell sap of the vacuole as the denser fluid of the osmotic pair. (See Physics.)

203. The development of the root system is related to the character of the soil and to the amount and distribution of water and organic matter within it. Branching of the root system is much more profuse in the moister parts of the soil, as well as in those which contain more organic matter.

204. Movement of water within the plant.—Once the water has gained entrance to the plant, it must move to those parts where it is to be used—i.e., to all the organs of the plant, but especially to the leaves, since from these there is the largest loss of water by evaporation (¶ 209). From the root hairs the water passes inward through the cells of the cortex, and reaches the stele. The forces which determine this movement and its direction are not fully understood, though osmosis probably plays a chief part. They are comprehended under the general phrase *root pressure.*

205. Root pressure.—The action of root pressure may be demonstrated by severing a suitable stem close to the ground and observing the water which flows out, after a short time, from the cut end. Careful examination of the cut surface will show that the water oozes out chiefly from the woody parts of the stele. The force with which water is extruded may be measured by attaching to the stump, by means of a rubber tube, a manometer (fig. 172). In this way it may be ascertained that in woody plants, such as the birch, the pressure sometimes becomes equal to that of five or six atmospheres.

206. Route to the leaves.—After entering the xylem bundles of the roots, the water is thence transferred along the stem in the same tissues, which are continuous with those of the root. Since the xylem bundles form an unbroken line to the most remote parts of the leaves, passing out in the ribs

and forming the finer veins, the water may be distributed to every part of the plant body. Within the wood it travels chiefly in the cavities of the large ducts or vessels, when these are present, though the walls, also, are saturated with it, and permit a slower movement. These ducts, although of great relative length (some up to 1 m.), are not continuous tubes like the veins of an animal, nor are they filled with water. The water is broken into short columns by numerous gas-bubbles, and in ascending to any considerable height must traverse many cell-walls.

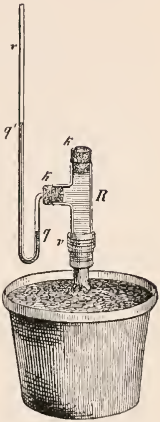


FIG. 172. — Apparatus for measuring root pressure. To the stump of a plant a T-tube, *R*, is attached by a piece of rubber tubing, *v*. The other openings are closed by rubber corks, *k*, through one of which passes a small glass tube, *r*, bent into two unequal legs, containing mercury. Through the upper should pass a short piece of glass tubing drawn out to a fine point, to be sealed off in a flame after *R* is filled with water. At the beginning of the experiment the mercury is about at the same level in both legs. As water is forced from the stump into *R* by root pressure the mercury rises in the arm *q'* and falls correspondingly in *q*.—After Sachs.

207. Motive power.—The force by which water is raised in the larger plants remains yet to be ascertained. The water does not flow along the ducts in a continuous current, as the blood in the veins, propelled by a force behind, for root pressure is not adequate to push it to the height attained. On the contrary, during the times of most active evaporation from the leaves, i.e., when the greatest supply is needed, root pressure becomes almost or quite negative. Capillarity is also inadequate. The diameter of the largest ducts is too small and the friction of the water against their sides consequently too great to permit the movement, by this means, of a sufficient amount of water to supply the evaporation. Moreover, the interruption of the water columns by gas-bubbles produces surface tensions which quite overcome that

of capillarity. It has been found that the bubbles of gas here mentioned often exist under negative pressure, as shown by the fact that a stem cut under mercury allows the mercury to ascend for some distance within the vessels. This negative pressure of the gases is due to the evaporation of water from the leaves, and the most recent researches point to this as a very important or even the chief factor in lifting the water. That the movement is not a function of living cells is shown by experiments in which stems of plants have been subjected to poisonous agents, or heated for many hours to a degree sufficient to kill all the living cells, yet without materially affecting the supply of water.

208. The loss of water.—Water is constantly evaporating from the whole surface of the plant exposed to the air. Since this loss is probably more or less modified by the vital activity of the plant, it has received the special name, transpiration.

209. Transpiration.—In the higher plants transpiration from the surface is reduced by the waterproofing of the epidermis, so that most of it takes place from the surfaces of internal cells into the intercellular spaces, wherever these exist. Since the intercellular spaces are connected with each other and also, through the stomata, with the outside air, water vapor is constantly passing off by diffusion. The leaves, affording the largest exposure, are especially organs of transpiration. After they have become fully expanded no appreciable amount of water is lost directly from their surfaces.

210. Amount and regulation.—The amount of transpiration, therefore, varies with the structure of the leaf rather than with its area. The temperature, percentage of water and movements of the air affect profoundly the rapidity of transpiration. Hence arises the need of regulation by the plant, to prevent excessive loss. The guard cells of the stomata are irritable, so that external conditions affect their

turgor. If both are turgid, they become curved away from each other so as to increase the size of the opening between them. If they are flaccid, the thick ridges along the inner face of each cell straighten them, and so close the orifice more or less completely (figs. 161, 162). The presence or absence of hairs upon the leaves, the existence of stomata upon one or both surfaces, the sinking of the guard cells below the general leaf surface, the distribution of the stomata, the thickening of the leaves, their inrolling (fig. 357), or revolution (fig. 359), have a decided effect upon the rate of transpiration, and may be adapted to regulate it. (See ¶ 434 ff.)

B. Foods in general.

211. Foods.—In addition to an adequate supply of water, food is required. Materials consumed by plants as food are either organic or inorganic. Organic materials are those which have been produced in nature by the chemical changes occurring within living bodies. Inorganic materials are those formed in nature by chemical reactions not occurring in connection with a living body. A very few of the simplest plants (bacteria) have been grown by the use of inorganic materials alone; only the minutest quantities of such substances are utilized by most plants as food; but large amounts are used by all green plants for the manufacture of organic foods.

Organic foods are of three kinds, carbohydrates, fats, and proteids.

212. Carbohydrates are substances consisting of carbon, hydrogen and oxygen, so proportioned that there are 6 carbon molecules (or some multiple of 6) while the two latter elements are combined in the ratio of two parts of hydrogen to one of oxygen. Well-known examples are sugars and starch.

213. Fats.—These are likewise combinations of the same three elements, but in them the hydrogen and oxygen do not exist in the ratio of two to one, the oxygen being much less in proportion. Some are solid at ordinary temperatures, while others are fluid. They are combinations of free fatty acids and glycerin. Upon the addition of an alkali, the fatty acids combine with it to form soap and other compounds of less amount while the glycerin is set free. Commercial examples of plant fats are olive oil, linseed oil, and cacao butter.

214. Proteids are foods consisting of at least five and generally of six elements, namely, carbon, hydrogen, oxygen, nitrogen, sulfur, and (ordinarily) phosphorus. These elements are complexly combined in varying proportions. Proteids are generally recognizable by their property of coagulation upon the application of heat, acids, or other agents. Well-known examples are the proteids forming the "white of egg." Examples from the vegetable kingdom are less familiar.

Proteids always, and either carbohydrates or fats, or both, must be available in order that a plant may be properly nourished. Green plants obtain their food chiefly by manufacturing it out of inorganic materials taken into the plant body from without. They are the only organisms, so far as known, which have the power of building up organic material from inorganic. They are, therefore, the ultimate source of the food supply of the world.

215. Metabolism.—After suitable foods become available to plants, whether by manufacture or by absorption ready-made, they suffer various chemical changes both before and after becoming a part of the body. The changes by which foods are manufactured and assimilated and those by which the products of waste are gotten rid of are all comprehended under the term metabolism.

C. Nutrition of colorless plants.

216. Colorless plants.—By this really inaccurate phrase are meant plants which do not possess chlorophyll, though some of them are highly colored by other pigments.

The colorless plants among the thallophytes constitute two large groups, known as bacteria and fungi. Among the seed plants, also, are found some devoid of chlorophyll.

Many plants possessing chlorophyll show to the eye other tints than green, when other pigments are present in such quantity as to mask the green. This is notably the case with the so-called "foliage plants," in which reds, yellows, purples, and browns are common. (See also ¶¶ 11, 40, 45.)

Colorless plants necessarily live either upon the decomposition products of dead organisms, or in company with living organisms. Those which live upon dead bodies, whether these have lost their form completely or not, are known as *saprophytes*. Those organisms which live in association one with another are called *symbionts* and their relation is known as *symbiosis*. (See Chap. XXIV.) Some symbionts are antagonistic and stand in the relation of parasite and host, the name parasite being applied to the organism which depends for its food upon the supporting organism, called the host.

217. Saprophytes and parasites may be either obligate or facultative. Obligate parasites or saprophytes are those which can exist only upon living or upon dead organisms, respectively. Facultative parasites or saprophytes are those which can pass a portion of their existence upon decaying or upon living organisms, respectively. They are not able, however, to complete their life cycle except upon their appropriate substratum.

218. Saprophytes.—Saprophytic bacteria live immersed in solutions of organic material, or surrounded by films of

fluid on the surface or in the interior of the organic material upon which they flourish. Saprophytic fungi either form their mycelium upon the surface of the organic matter, or, more commonly, they penetrate it more or less extensively by a profusely branched system of submerged hyphæ. A few saprophytic seed plants form at the base of the stem an enlarged, tuber-like mass from whose surface great numbers of profusely branched roots arise. These penetrate the decaying material in all directions, and act as absorbing organs. A few have abundantly branched underground stems and have no permanent roots.

219. Digestion.—Saprophytes whose surfaces are surrounded by food solutions have only to absorb them. Some, however, have power to convert into material soluble in water the solid insoluble foods with which they are in contact. This is brought about either by a direct action of the protoplasm of the living plant, or by means of *enzymes* (¶ 237) excreted by it. Such chemical changes, by means of which insoluble solid materials are transformed into soluble ones and are dissolved, are quite like those which occur in the digestive tract of the higher animals, and, therefore, may be properly termed digestion.

220. Assimilation.—After the food is absorbed, it undergoes various changes, collectively known as *assimilation*, by which it is enabled to become part of the living material of the plant body.*

221. Fermentation and putrefaction.—Some saprophytes produce changes in the material upon or in which they grow, other than those described above. The more important changes may be comprehended under the two terms fermentation and putrefaction. Between these there is no sharp

* This is not to be confused with the manufacture of organic food by green plants, to which the term assimilation is inaptly applied by most writers.

line of demarcation. Popularly the term putrefaction is applied to the changes in nitrogenous substances which are accompanied by offensive odors. Fermentation is commonly applied to the chemical changes occurring in sugary solutions, such as fruits, expressed juices, infusions, etc. Many bacteria and a number of fungi, notably those known as yeasts, are capable of producing fermentation in such solutions. The chemical changes produced are more extensive than those required for obtaining food. Ordinary brewer's yeast, for example, utilizes about 5 per cent of the sugar present in the solution for food, but breaks up the remaining 95 per cent into carbon dioxide, alcohol, and some other less important by-products. In putrefaction the by-products are commonly offensive gases, among which hydrogen sulfid (H_2S) predominates. Various other materials may be formed, among which not infrequently are virulent poisons. These are well known in certain putrefactive changes of milk, meat, etc.

222. Parasites obtain their food either by growing upon the surface of the host and thrusting into its interior absorbing organs; or by growing wholly in the interior of the host, breaking out to its surface only to form reproductive bodies.

Parasites may work little apparent harm, or they may bring about local disease and death of the host. Their mode of obtaining food is not essentially different from that of saprophytes. They either digest solid foods, or absorb liquid foods, prepared by the host for its own use. Among the green plants there are some partial parasites, such as the mistletoe, which seem to obtain from their hosts chiefly the water and salts which they have absorbed. These materials they themselves elaborate into food. (See further ¶ 465.)

D. Nutrition of green plants.

223. Raw materials.—In order that the green plants may be able to manufacture their food, they require certain raw

materials, which are obtained from the medium by which they are surrounded. These substances are a weak watery solution of various mineral salts, and a gas, carbon dioxide.

224. Salts absorbed.—Along with the water which is taken into the plant go various amounts of dissolved material, a considerable portion of which consists of mineral salts. When plants grow in humus, or in water or soils containing organic matter, a variable amount of carbon compounds suited for food may be dissolved by the water and be taken up by the plant. To this extent the plant will live as a saprophyte, and no doubt many field and garden plants have been bred to require this sort of life. Among the mineral salts the most important are the salts of calcium and magnesium, which are present in all soils, in greater or less quantity, usually in the form of nitrates, phosphates, and sulfates. Compounds of two other indispensable elements, namely, iron and potassium, are dissolved in soil waters. In the same way at least seven additional elements are obtained by plants. Besides these, other compounds to a considerable number, of no use in forming food, are taken in. Silicon, for example, which is found in the ash of almost all plants, is of no value either as a food, or for the manufacture of food, although it plays an important rôle in increasing the rigidity of certain plants, and in protecting others from injury.

225. Selective action.—Compounds of these elements exist in the water in various, though small, amounts. But they are not taken into the plant in the same proportions as they exist in the water. For each substance presented to the plant there is a certain degree of concentration at which its solutions are absorbed with greater rapidity than at any other. Substances which are utilized by the plant and which, therefore, disappear as such within it by having their chemical composition altered or by being stored up in a different form and so removed from solution, will enter the plant contin-

uously so long as the supply outside exists. Substances absorbed by the plant and not utilized accumulate, and their solutions soon attain the same degree of saturation within the plant as outside, when they cease to be absorbed. It is for this reason that two plants growing upon the same soil may contain very unequal quantities of any important material. Plants thus exert a sort of selective action, but this selection is dependent upon purely physical laws, and is not directly under the control of the plant.

226. Carbon dioxide.—Carbon dioxide, as such, is not found in nature. It instantly combines with water to form a gas known as carbonic acid gas, and this is ordinarily meant when carbon dioxide is spoken of. This gas exists in small quantities in the atmosphere, rarely exceeding one part in twenty-five hundred, except in secluded spaces. The constant currents in the atmosphere make its distribution practically uniform. On account of its ready solubility, this gas also exists in abundance in soil waters and in the larger bodies of water constituting streams, lakes, or pools. In a soil containing carbon compounds it is constantly being produced by decomposition. The water which passes through the soil therefore has a larger percentage of this gas than the air, sometimes containing as much as one per cent.

227. Absorption.—Water plants readily absorb the dissolved gas by such surfaces as are exposed to the water. Floating plants have opportunity to obtain it both from the water and from the atmosphere. Land plants, although their roots are surrounded by a comparatively concentrated solution of carbonic acid, do not take up appreciable quantities by these organs. On the contrary, the absorption of this gas seems to depend entirely upon those cells which contain chlorophyll. The stomata, which allow the internal intercellular spaces free communication with the outside air, are important organs, not only in regulating transpiration,

but also in permitting the absorption of this gas. Its continued absorption depends upon its continuous removal from the cell sap in the manufacture of carbohydrates.

228. Anabolism.—By this term are designated the constructive processes of metabolism, by which complex substances are produced from simple ones. These materials belong chiefly to two classes, (*a*) carbohydrates, (*b*) proteids.

229. 1. **Carbohydrates.**—The process by which carbohydrates are produced is called *photosyntax*. The conditions under which photosyntax occurs are three: (*a*) the presence of chlorophyll, (*b*) the action of light, and (*c*) the presence of potassium salts.

230. (*a*) **Chlorophyll.**—Chlorophyll, as has been shown in Part I, sometimes colors the whole protoplasm of the cell, but is more commonly found only in certain special structures, the chlorophyll bodies. The real work of forming the carbohydrate depends, therefore, upon the protoplasm of the chlorophyll body. The purpose of the chlorophyll is to absorb certain portions of the light which falls upon it. If the light which has been passed through a green leaf, or a solution of chlorophyll, be examined with a spectroscope, seven dark bands appear in place of certain of the colored rays, because these have been stopped by the chlorophyll (fig. 173). One absorption band lies between the red and the orange (3–9 of scale, fig. 173), another in the orange (11–14), the third, faint, in the yellow (17–20), the fourth at the edge of the green (30–32), while the fifth (53–73), sixth (75–93), and seventh (94–100) bands occupy most of the blue and violet. These last three blend into one extremely broad band, except when the light passes through very small quantities of chlorophyll.

231. (*b*) **Light.**—The light absorbed by the chlorophyll furnishes the energy necessary to carry on the work of taking apart the carbonic acid and rearranging the molecules into a

more complex substance. This energy cannot be supplied by the plant itself. An external source of energy is therefore necessary. What this source is is unimportant, provided the

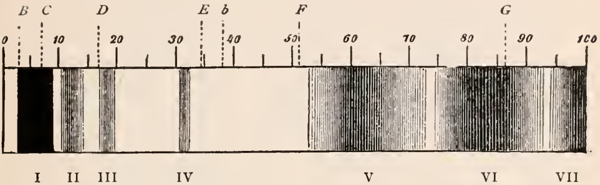


FIG. 173.—The absorption spectrum of an alcoholic solution of chlorophyll. A beam of sunlight passed through a prism is broadened into a strip, called the spectrum, which shows different colors, according to the length of the light waves, the longest appearing red and the shortest violet. Some of the light waves are stopped by absorption, and at these places black lines appear (Fraunhofer lines), the more important being those below the letters *B*, *C*, etc. When the sunlight passes through an alcoholic solution it absorbs those parts of the light corresponding to the dark bands I to VII. These absorption bands are made visible by spreading out the light ray into a spectrum. The bands are located by the Fraunhofer lines, or by the artificial scale, or roughly by the colors.—After Kraus.

energy be sufficiently intense. The light of an electric arc serves the purpose as well as sunlight, if its intensity be equal.

232. (*c*) **Potassium salts.**—These take no part in the composition of the food produced, and their exact rôle is not understood. It is well established, however, that their presence is essential to the formation of the carbohydrate.

233. The product of photosyntax.—The steps in the process of the building of carbohydrates are not thoroughly known. Present indications are that the material first produced by the rearrangement of the molecules of carbon, hydrogen, and oxygen, derived from the carbonic acid, is a molecule of the simplest carbohydrate, formaldehyde, CH_2O. Several of these are then built up (by condensation and polymerization) into one of the more complex carbohydrates, such as cane sugar. Starch is generally the first visible product and appears as minute granules in the interior of the

chlorophyll bodies, but is probably a transformation product from a sugar, to which it is closely akin chemically.

234. 2. **Proteids.**—The formation of proteids is even more obscure. Apparently at some point in the series of changes following the formation of formaldehyde, molecules of nitrogen are added to form an amid. Amids, especially asparagin, leucin, and tyrosin, are common in plants. They may also be produced by the use of carbon, hydrogen, and oxygen from complex carbohydrates by katabolism (¶ 238). They are soluble in water, crystallizable, and, hence, can be carried by osmosis from cell to cell. From these, by the addition of sulfur and phosphorus, proteids are formed, but neither the steps in the process nor its conditions are well understood. Apparently the formation of amids occurs in green tissues and under the influence of light. It is probable that even among the green plants the formation of proteids takes place in other parts than the green tissues, as it is certain that this occurs also among the colorless plants. The proteids which are built up from the amids are used directly in the repair of protoplasm. Since carbohydrates are necessary to the formation of proteids, and since they can be manufactured only by the green plants under the influence of light, it will be seen how essential these plants are for the world's food supply.

E. Storage and translocation of food.

235. Storage and transfer.—Both in the colorless and green plants it is necessary that the foods made or absorbed should be transferred from one point to another where they are to be used. The larger the plant, the more important does this transfer become. In many plants, also, it is desirable that a supply of reserve food be stored for use when a supply is no longer available from the outside or by manufacture.

236. Storage.—In the higher plants storage places are secured by the enlargement of roots, stems or leaves, to form

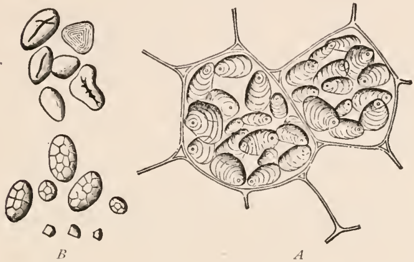


FIG. 174.—Reserve starch. *A*, two cells of a potato, showing enclosed starch grains The other contents not shown. *B*, compound starch grains from a grain of oats Three of the component granules of a large grain are shown separately. *C*, starch grains from a bean. All highly magnified.—After Kerner.

reservoirs. Similar specialization of parts of lower plants occurs. Carbohydrates are sometimes transformed into fats for storage purposes, but carbohydrate and proteid reserve food is usually solid. Reserve carbohydrates usually occur in the form of starch, sugar, cellulose, gum, etc. Reserve proteids are usually in the form of aleurone grains. The starch is deposited in the form of large rounded or oval grains (sphere-crystals), which often show layers of different composition and density (fig. 174). Fats occur in liquid form as droplets of various size, and are only rarely solid. Aleurone grains are really vacuoles filled with reserve proteids. Some of the proteids often

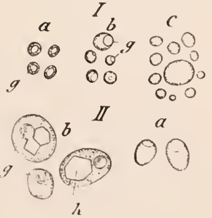


FIG. 175.—Aleurone (proteid) grains. *I*, from seed of peony. *a*, from the outer, *b*, from the middle, *c*, from the inner layers. *II*, from seed of castor bean. *a*, in alcohol; *b*, after treatment with iodine solution and alcohol. In both, *g*, globoid; *k*, crystalloid. Very highly magnified.—After Zimmermann.

crystallize (producing a crystalloid), and other materials are frequently present, which form the globoid (fig. 175).

237. Intracellular digestion.—When solid foods, insoluble in water, are to be moved from one part of the plant to another it must be done by altering them into soluble substances. This is accomplished by means of enzymes of different kinds, adapted to effect the alteration of various foods. The most abundant enzyme is diastase, which has the power of altering starch into a sugar called maltose. Enzymes fitted to transform proteids are also found in considerable amounts. When the foods have thus been brought into a soluble condition, they dissolve in the water present and move from one part of the plant to another, chiefly by osmosis. As any given material is used up in growth or repair, or is altered into another substance, a constant stream of molecules of this material moves toward the point at which it is disappearing. Thus from the food sources it is transferred to the reservoirs and stored in suitable form. Thence, when needed, it is redissolved after digestion and carried to the active parts which utilize it.

F. Katabolism.

238. Destructive changes.—Coincident with the processes which result in the formation of complex organic substance out of simpler ones are those which result in its destruction. The constructive processes are grouped under the term *anabolism*, and the destructive ones are designated as *katabolism*. In the green plants the anabolic changes predominate (because of extensive photosyntax), with the result that the plant accumulates organic matter; while in colorless plants katabolic processes predominate, with the result that the plant increases in bulk, but only at the expense of organic materials previously existent. In all plants, however, both the con-

structive and destructive changes go on at the same time and without conflict.

239. Respiration.—A series of katabolic changes is included under the term *respiration*. It is a familiar fact that the higher animals cannot live without a constant supply of oxygen and a corresponding excretion of carbon dioxide. This is not so generally known to be true of plants. It is, nevertheless, true that no plant can live without a constant supply of oxygen and a corresponding excretion of carbon dioxide. The processes by which oxygen is obtained and carbon dioxide excreted constitute respiration.

240. Respiratory ratio.—The ratio between the amount of oxygen consumed and carbon dioxide produced varies somewhat with the age and condition of the plant, as well as with the circumstances under which respiration occurs. Ordinarily the volume of carbon dioxide produced is approximately equal to the volume of oxygen consumed, and the ratio may be expressed thus: $\frac{CO_2}{O} = 1$.

241. Respiration and photosyntax.—In the green plants respiration is masked in daylight by photosyntax. Whenever the green parts are sufficiently illuminated, the carbon dioxide produced by their respiration is consumed in the formation of carbohydrates for food. But when these parts are not adequately illuminated, the process of photosyntax is interrupted, and respiration can be studied. The parts of plants which are free from chlorophyll, such as young flowers, buds, embryos, and the like, and all the non-green plants, allow the respiratory changes to be demonstrated readily.

242. Aeration.—The oxygen consumed comes from the atmosphere, or from the molecules of this gas dissolved in water. Certain plants are adapted to aerial respiration, while others are adapted to aquatic respiration, but in either case

the gas used is the same. In the smaller and simpler plants the protoplasm absorbs oxygen directly through the cell wall. In multicellular plants, however, especially when these become large and complex, only the superficial cells could do this. The internal cells are too far from the source of supply to allow an adequate amount of oxygen to reach them by osmosis through other cells. In large plants, therefore, intercellular spaces are provided, communicating with the external air, and through these oxygen diffuses. In the land plants the intercellular spaces are continued through the epidermis, in which, with the guard cells, they constitute the stomata (¶ 166). On the older parts of woody plants which have begun to form a periderm the stomata are replaced by lenticels, through which the internal intercellular spaces communicate with the outer air (¶ 140). In the absence of stomata or lenticels, however, the oxygen may pass through any part of the surface of the plant. In submerged water plants, very large intercellular spaces are formed (fig. 117), permitting the existence of an internal atmosphere of considerable amount, within whose limits gaseous exchanges may occur. Oxygen may reach these intercellular spaces from the water through the superficial cells.

243. Intramolecular respiration.—While free oxygen is ordinarily utilized for respiration, all plants seem to be capable of obtaining their supply for a short time from the organic matter of the plant itself. Such respiration has therefore been called intramolecular respiration. It can exist at most for a few hours without producing disease and, sooner or later, the death of the plant. It is precisely parallel to the similar method of respiration possible among cold-blooded animals. A few plants of the simpler sort, such as the bacteria, rely wholly upon combined oxygen for their respiratory supply. Such plants have adapted themselves to grow in the absence of free oxygen, which, instead of facilitating

their life processes, really checks them. They are known as anaerobic plants.

244. Excretion.—The carbon dioxide produced by respiration, when not used for photosyntax, is gotten rid of by the reverse of the methods described for the absorption of oxygen.

245. Release of energy.—The purpose of respiration is to set free energy required for growth and movement. While plants are capable of utilizing radiant energy of the sun for photosyntax, they must set free within their own bodies the energy requisite for putting in place particles of new material to form new parts, and for the execution of movements, whether internal, such as the streaming or rotation of the protoplasm, or mass movements, such as those of leaves and other members, or movements of locomotion, such as those of swarm pores and sperm cells. (See ¶ 276 ff.) The required energy is set free by the decomposition of organic matter.

246. Loss of weight.—As a consequence there ensues a loss of weight. If a plant, such as a seedling abundantly supplied with reserve food, be compelled to develop in darkness, and so allowed to make no additional food, it may be easily demonstrated that a large part, often as much as one half, of its weight will be lost (as gases) in respiration. This loss of weight comes primarily from the decomposition of portions of the living protoplasm. These, however, are soon replaced by the formation of new protoplasm from the proteids, and these again are replaced, as already described, by the use of carbohydrates and nitrogenous compounds. Ultimately, therefore, respiration results in a diminution of the reserve food, especially of the carbohydrates.

247. A vital function.—Respiration is a function of the protoplasm, and does not occur simply because oxidizable substances are present in the plant and oxygen is brought

into contact with them. On the contrary, the oxygen seems to enter into loose combination with protoplasm, forming an extremely unstable compound which under unknown conditions breaks down into simpler substances, setting free energy. Some of these materials are again used in building protoplasm, while others break down still further, ultimately into water and carbon dioxide. The supply of oxygen is so necessary that if a plant cannot obtain oxygen from without, it will secure it by the destruction of part of its own substance for a time, as shown by intramolecular respiration.

248. Heat.—While this decomposition of the protoplasm in ordinary respiration is not a true oxidation, it nevertheless results, as oxidation does, in the evolution of heat. The amount of heat produced is usually not great enough, and its loss too rapid, to make it readily perceptible. Anything which prevents the radiation of heat will make its measurement possible. The germination of large quantities of seeds or the blossoming of a number of flowers in a confined space may raise the temperature as much as 15 or 20° above that of the air. The heating of hay, grain, and similar substances, which have been stored when moist, is due partly to the respiratory activity of bacteria and fungi, which grow rapidly under these conditions. Fermentative changes, which also occur under the same conditions, add to the evolution of heat.

249. Light.—A few plants also produce light. This light is like that seen when phosphorus is exposed to the air in darkness, or when the end of a match is lightly rubbed. Phosphorescence occurs only in some bacteria and fungi. When it is seen upon decaying meat, fish, or wood, it is because these organisms are present. It does not arise from the decaying substance itself. Several of the larger fungi, as certain toadstools, have a mycelium capable of emitting this phosphorescent light.

250. Contrast between respiration and photosyntax.—Since the processes of respiration and photosyntax in green plants are so frequently confused, a contrast is here drawn between them.

Respiration.	*Photosyntax.*
Occurs in all living cells.	Occurs only in green cells.
Indifferent to or retarded by light.	Requires light.
Consumes organic matter.	Produces organic matter.
Produces carbon dioxide.	Consumes carbon dioxide.
Consumes oxygen.	Produces oxygen.
Sets free energy.	Accumulates energy.

251. Other katabolic changes.—Besides those constituting respiration, a considerable number of other katabolic changes occurr, which are not so closely connected with the vital functions of the plant. They result in the production of substances which are of no further use in nutrition and only of incidental value for any purpose. Such substances may be stored in some out of the way place, or in such parts as are transient, and by the loss of these parts the useless materials are gotten rid of; or they may be excreted directly. The waste materials are either nitrogenous or non-nitrogenous.

252. Non-nitrogenous by-products.—Among the non-nitrogenous materials the most important are the carbon acids, such as oxalic, malic, etc., the tannins, the resins, the gums and the volatile oils. These substances are either by-products of photosyntax, or they arise in the course of the assimilation of foods. Oxalic acid is usually gotten rid of by being combined with lime to form calcic oxalate, which crystallizes either in the form of squarish crystals or as long needles, the form depending upon the amount of water of

crystallization (fig. 176). The resins, usually dissolved in an oil, are generally excreted into special intercellular spaces

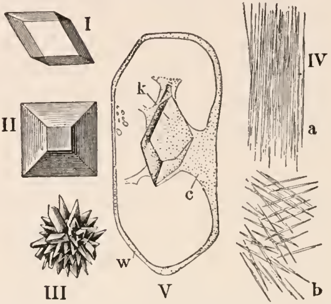


FIG. 176. Crystals found in plants. I, calcium carbonate; II–V, calcium oxalate; II, octahedron with blunt ends; III, compound crystals from the nectary of a mallow; IV, *a*, *b*, needle crystals (raphides) from leaf of fuchsia; V, cell from the fruit-flesh of a rose showing a crystal, *k*, embedded in an outgrowth of the cell-wall, *c*. All highly magnified.—After Behrens.

(fig. 177). Volatile oils are secreted by glandular hairs (*c*, fig. 113); or are formed in the epidermis itself, as in flowers; or are produced in chambers near the surface, the cells which produce the oil being disorganized to form the cavity in which the drops lie (fig. 178). Other materials, such as salts of lime, are sometimes

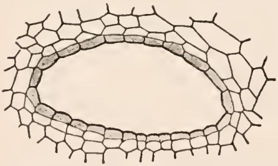


FIG. 177.—Transverse section of an intercellular receptacle for gum-resin from the fruit of fennel. The secretion has been dissolved out by alcohol. The shaded cells lining the tube are the secretory tissue. Moderately magnified.—After Tschirch.

excreted upon the surface of the plant. From glands in the flower, nectar, which is a solution of sugar, is excreted (figs. 179, 180). The loss of this food is compensated for by its attractiveness for insects, which incidentally serve for the transfer of pollen from one flower to another. Caout-

chouc and gutta-percha occur in the milky juice of certain plants.

253. Nitrogenous by-products.—Among the nitrogenous waste materials the most important are the alkaloids, such as

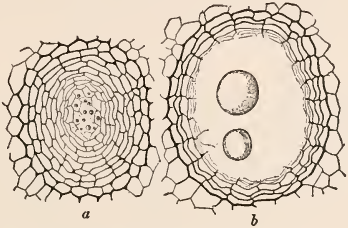


Fig. 178.—Section through oil-receptacles in rind of orange. *a*, structure at the beginning of the disorganization of the oil-producing cells; *b*, final condition, with two drops of oil occupying the cavity. Moderately magnified.—After Tschirch.

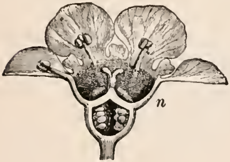


Fig. 179.

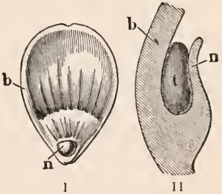


Fig. 180.

Fig. 179.—A flower of the red currant cut in half. The roughened surface of the cup, *n*, secretes nectar. Magnified 5 diam.—After Kerner.

Fig. 180.—I, a petal from the flower of a buttercup (*Ranunculus acris*), showing the nectary, *n*. Magnified 3 diam. II, diagram of a longitudinal section of the same through the nectary *n*. The tissue lining the pouch of the petal, *b*, secretes the drop of nectar, *t*. Magnified 8 diam.—After Behrens.

quinine, morphine, strychnine, nicotine, etc., which occur in the seeds, bark, or leaves, and are gotten rid of when these are dropped.

CHAPTER XIV.

GROWTH.

254. Definition.—The growth of plants is continued for a much longer time than that of animals. In most cases it is continued in some part throughout the existence of the plant. There are also changes in the form of certain parts, particularly of the lower plants, which must be distinguished from true growth. Growth is a permanent change of form accompanied usually by an increase in size.

255. Formation of new parts.—Each new cell originates in the division of some previously existing cell by a partition-wall.* The two cells so formed grow until they attain the size of the parent cell, when one or both may continue to grow until they attain a permanent form; then growth ceases. Those cells which do not develop into permanent tissue, but retain their power of division, constitute a mass of tissue at the tip of each branch or root, the primary meristem (¶ 77, 101). Permanent tissue which resumes active division is called secondary meristem (¶ 86, 134). It will be seen, therefore, that every cell of a plant has been at some time in an undeveloped or *embryonal* condition.

256. Phases of cell development.—The characteristics of this embryonal condition are the nearly uniform and small size of the cells, the relatively large nuclei, and the absence or small size of the vacuoles (*A*, fig. 181). As the cells which are destined to become the permanent tissues grow older

* To this there are only unimportant exceptions.

they pass gradually from the embryonal stage into a second phase of development, the stage of elongation. This stage is marked by the rapid increase of the cells in size and a much less marked increase in the mass of protoplasm present. In order to maintain the turgor of the cells, there is a great increase in the volume of water, which accumulates in one or

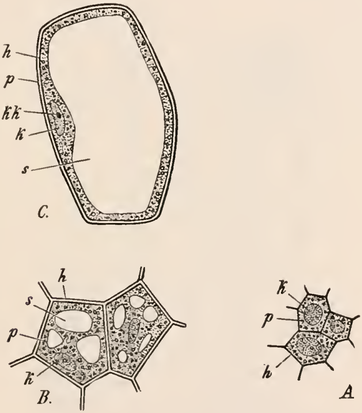


FIG. 181.—Cells from young and mature fruit of snowberry (*Symphoricarpus*), seen in section. *A*, three young cells, very small, walls thin, nuclei relatively large, vacuoles very minute; *B*, two, somewhat older, larger, walls thicker, nuclei smaller, vacuoles several. *A* and *B* magnified 300 diam. *C*, a single cell, mature, magnified 100 diam., one third as much as *A* and *B*; vacuole single, very large. The volume of *C* is more than 1500 times one of the cells in *A*. *h*, cell-wall; *p*, protoplasm; *k*, nucleus; *kk*, nucleolus; *s*, vacuole.—After Prantl.

more large vacuoles (*C*, fig. 181). If the organ in question has an elongated form, such as the stem or the root, growth of the cells takes place chiefly in the direction of its long axis, although an increase also occurs in the transverse directions. During this phase the cells may attain a hundred or even a thousand times their former volume. Growth in length can

be studied by direct observation with a microscope, but more conveniently by magnifying the growth by mechanical means, so as to observe the movements of a pointer over a scale. Such an instrument is an auxanometer. Those forms of it which secure a continuous record automatically are of the

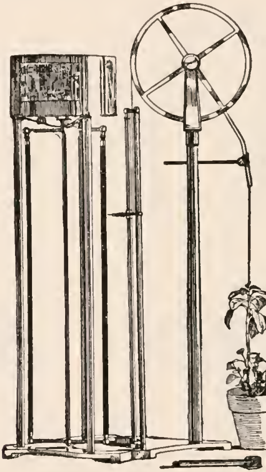


FIG. 182.—Golden's auxanometer. The instrument consists of two parts, a multiplying pulley and two recording rods turned by a clock. A thread from the plant passes through a bent glass tube and makes one turn around the small pulley to which it is then fastened. Another thread makes one turn around large pulley and descends to carry a pointer which slides on two guide rods. As the plant grows the thread from it slackens and the pointer descends at a magnified rate by its own weight. Two glass rods, blackened in a smoky gas-flame, are rotated by a clock to whose hour-spindle the frame carrying them is attached. As they pass the pointer a mark is made on the smoked surface. The distance of the successive marks shows the amount of growth as magnified. Permanent record may be made by means of blue prints, using the rods (which are removable) as negatives.—After Arthur.

most service (fig. 182). By imperceptible gradations these cells pass into the third and final stage of growth, which is

characterized by permanent and usually irregular thickenings of the wall (figs. 10, 11, 52, 58).

257. Grand period of growth.—The entire duration of growth of an organ is known as its grand period of growth. Corresponding precisely to the phases in cell development, there are three phases in the development of the organ as a whole. Its growth is at first very slow, increasing gradually, and then more rapidly, to a maximum, from which it falls rapidly, and then more gradually, until it ceases entirely. The earliest phase, the embryonal, results in so little elongation that it is scarcely possible to have it recorded by the auxanometer. The last phase, that of internal differentiation, is not

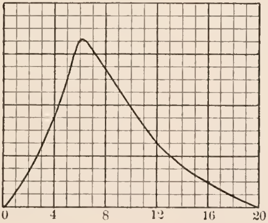


FIG. 183.—Curve representing the rate of growth of an internode of crown imperial for each day during the grand period—in this case 20 days. The height of each vertical line where it intersects the curve represents the total growth for the corresponding 24 hours. The numbers indicate days. The maximum growth occurred on the 6th day. —After Sachs.

marked by any elongation. The accompanying curve (fig. 183) therefore represents only the duration and course of the phase of elongation.

258. Growing region.—The part of any one of the multicellular plants, which is growing in length, is limited. The elongating region of a root rarely exceeds a centimeter, and is often not more than one half a centimeter in length. In

stems, however, the elongating part may measure twenty or even fifty centimeters, and in rare cases much more. Figure 184 shows a root, *A*, upon whose surface marks were made 1 mm. apart. Twenty-four hours later the root presents the appearance of *B*. Only the tissues in the first five spaces were capable of elongation. The others had passed into the third phase. The second and third millimeters grew most in length. The growing regions of stems may be determined in the same way.

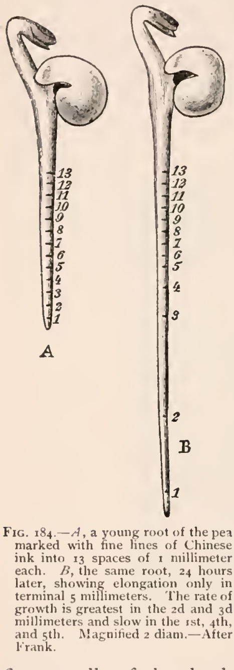


FIG. 184.—*A*, a young root of the pea marked with fine lines of Chinese ink into 13 spaces of 1 millimeter each. *B*, the same root, 24 hours later, showing elongation only in terminal 5 millimeters. The rate of growth is greatest in the 2d and 3d millimeters and slow in the 1st, 4th, and 5th. Magnified 2 diam.—After Frank.

259. Tension of tissues.—The different tissues in any organ usually do not grow at an equal pace, and consequently certain tissues are under strain, while others are compressed. The curled and crinkled leaves or the curved capsules of mosses illustrate this inequality. It may be present, however, without manifesting itself in external form. This general condition is known as the *tension of tissues*. If the rapidly growing flower-stalk of the dandelion or the leaf-stalk of rhubarb be carefully split lengthwise the parts will curve or even curl outward. Separating the inner and outer tissues of a young elder shoot and carefully measuring them shows that the inner tissues elongate and the outer actually shorten. The experiment, therefore, shows that the inner tissues really grew more rapidly than the outer, but were compressed in

the uncut stem, while the outer ones were slightly stretched. The strains thus set up are spoken of as longitudinal tissue tensions. Similar tensions due to unequal transverse growth may be shown to exist. If a thin transverse slice from the fleshy leaf-stalk of the rhubarb be divided into equal parts by a longitudinal cut it will be found in a few moments that the halves can no longer be made to touch throughout the line of the cut, because it has become convex. Both the longitudinal and transverse tensions may be exaggerated if the parts be placed for a few moments in water.

260. Conditions of growth.—That plants may grow certain conditions are prerequisite. (1) There must be an *adequate supply of constructive materials.* These may be derived either from food recently manufactured or from that stored in reservoirs, or, in the case of the colorless plants, from that absorbed from without. (2) There must be a *supply of oxygen* for respiration. This is needed, as previously explained, to set free the energy necessary for growth. (3) There must be a *supply of water* adequate to maintain a minimum turgor of the cells, without which growth cannot take place. (4) A *suitable temperature* is required. The range of temperature within which growth may take place is extensive, and varies with the individual plant. In general, the upper limit may be stated as about 40° C., and the lower, about 0° C. The minimum of plants of tropical regions is approximately 10° C., while the maximum for plants of the arctic or alpine regions is much below 40° C. Between the maximum and minimum temperatures there is an optimum temperature for each plant, at which growth takes place most rapidly. For most plants the optimum lies between 25° and 32° C.

261. External conditions exercise a very important influence upon the rate or character of growth by reason of the irritability of the protoplasm. (See further ¶ 418.) Many of these conditions act upon members of the plant so as either

to bring about permanently unequal growth in a certain part, or to cause one part to grow more or less rapidly for a time than another. Such variations in growth produce curvatures in the parts concerned and move members connected with them. They are therefore discussed in the chapter on Movements. Those conditions which act more generally and uniformly upon a large number of plants have a tonic effect and serve to determine the form and mode of development of members.

262. Light.—The tonic effect of light is different upon different plants and even different members of the same plant.

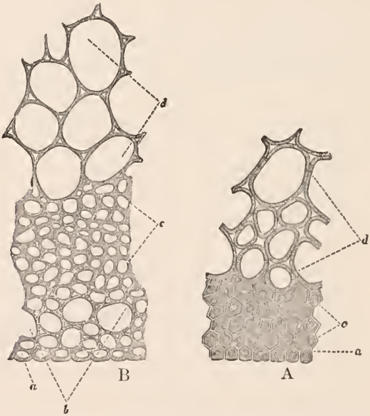


FIG. 185.—Part of the transverse sections of the stem of rye. *A*, from a plant grown fully exposed to light; *B*, from a "laid" plant imperfectly exposed to light. *a*, epidermis; *b*, *c*, mechanical tissues; *d*, thin-walled tissues. Highly magnified.—After Koch.

In general light retards growth in length. Stems grown in darkness usually become excessively elongated. Those which under normal illumination have internodes very

short, in diminished light may have them well developed, as occurs, for example, in dandelions growing in deep shade.

In general, light accelerates the growth of leaves in area. Leaves of shoots grown in darkness remain small.

Light affects not only the external form but the internal structure. In diminished light the cell walls do not thicken normally, and mechanical tissues are weakened. "Laying" of oats and such grasses is mainly due to this cause (fig. 185). In weak illumination the palisade tissue of the leaves (¶ 167) is poorly developed.

263. Light and temperature.—The combined variation of light and temperature between day and night establishes a *daily period* in the growth of all plants. The withdrawal of light at night permits an increase in the rate of growth in length, which reaches its maximum in some plants shortly after midnight, in others not until the early morning. During the day its retarding effect diminishes the rate of growth, which reaches a minimum some time in the afternoon. The

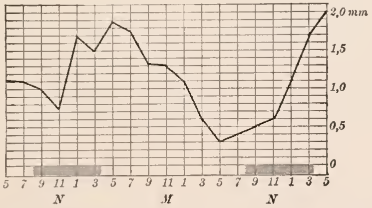


Fig. 186.—Curve showing the daily period in the growth of a stem of rye. The vertical lines represent 2-hour periods from 5 P.M. of one day to 5 A.M. of the second day, the shaded parts indicating the actual hours of darkness. The horizontal lines represent tenths of a millimeter. The curve is drawn by taking the record from an auxanometer and laying off on the vertical line for each interval the growth shown. The points are then joined. It will be observed that the maximum rate of growth occurs shortly after the period of darkness (5 A.M.) and the minimum rate after the period of most intense illumination (5 P.M.). During the experiment the thermometer varied from 18° to 22° C.—After Frank.

minor fluctuations in temperature, as well as the generally higher temperature during the day and lower during the night,

introduce variations in the rate of growth, which obscure, but do not counteract, the retarding influence of light. (See fig. 186.) This daily period is so impressed upon the constitution of the plant that it maintains it for a considerable time even when kept in complete darkness. Stems of sunflower, after two weeks in complete darkness, still showed distinctly the daily period. A similar daily period is apparent in the tension of tissues which depends on growth.

FIG. 187.—A shoot of water crowfoot (*Ranunculus aquatilis*). The lower leaves have developed under water and are branched into many narrow divisions; the two upper leaves have developed in air and at maturity float on the surface of the water. About half natural size.—After Frank.

264. Moisture and oxygen.—The amount of moisture and oxygen present in the medium surrounding a plant profoundly affects its form. Amphibious plants, that is, those which are capable of growing either on land or in water, often show this in a striking way. When grown submerged, the leaves are usually finely divided, while the same leaves, if allowed to develop in the air, have broad blades scarcely more than lobed (fig. 187).

265. Mechanical pressures or strains also exert an influence upon the rate and mode of growth. Compression of tissues retards their growth; strains accelerate it. Thus, stems enclosed in plaster casts or ligatured grow more slowly in thickness. Tensile strains, such as those exerted by wind or weight, promote the development of mechanical tissues. Petioles, which would break under a strain of 700 gm., after enduring a pull of 500 gm. for five days, broke only at 1600 gm. After five days more under a strain of 1200 gm. they could not be broken with less than a weight of 6500 gm.

266. Variations in rate.—There are not only variations in growth in the course of each day throughout the growing

period, but also minor variations independent, so far as known, of external conditions, which are therefore called spontaneous variations. Irregular variations occur from hour to hour in the course of the day. Regular spontaneous variations, also, occur in various organs, particularly in the tendrils of climbing plants, and in the leaves of flowers and buds. These regular variations, which affect different sides of bilateral organs and different sectors of cylindrical ones, bring about a bending of the entire organ from one side to another. These curvatures produce nutation, and will be further described under movements. (See ¶ 283.)

267. Duration.—Even when the external conditions of growth are kept as uniform as possible, growth does not continue for an indefinite time. Having passed through the phases above named, it ceases, no matter how favorable the external conditions. Yet some organs, even after growth has ceased, may resume it, provided they are affected by suitable stimuli. Thus, the leaf cells which have long since ceased to divide may resume the power of division in the neighborhood of a wound, and by division and the growth of new cells may form a callus covering the wound. The stimulus following fertilization also induces growth in parts adjacent to the egg, as is most strikingly shown in the formation of fruits of the seed plants. (See ¶ 404, 409.)

CHAPTER XV.

THE MOVEMENTS OF PLANTS.

268. Irritability.—Among the fundamental properties of protoplasm are irritability and automatism. We know practically nothing of the nature of either of these properties, though upon them depend all the movements executed by plants. Automatism is the name given to the power in virtue of which protoplasm is able to initiate internal changes without the action of any external force. Irritability expresses the power of the protoplasm to respond or *react* to the influence of an external change.

269. Stimuli.—The external change which brings about the reaction is known as a *stimulus*, and its application is called *stimulation*. External forces which may act as stimuli are light, heat, gravity, moisture, electricity, chemical substances, etc. Most of these act constantly upon plants. In order that they may act as stimuli, therefore, a relatively sudden change in intensity or direction must occur. Sometimes, however, a slow change will still produce a reaction. For example, the gradual withdrawal of light may cause movements of leaves. (See ¶ 297.)

270. Conditions limiting irritability.—Protoplasm is irritable only under certain conditions, which coincide in the main with those that promote the general well-being or life of the organism. The limits of temperature, moisture, and the supply of oxygen, which permit irritability, are much narrower than those which permit life. Thus, irritability may be lost when the conditions are unfavorable, though life

may persist under such conditions for a long time. Irritability may also be lost through fatigue, as when, after repeated reaction, no response occurs to even a greatly increased stimulus. Upon the return of suitable conditions, or after sufficient rest, irritability may be regained.

271. Reaction.—The response of the protoplasm to a stimulus is out of all proportion to the physical or chemical action of the stimulus itself. The action of the stimulus upon the irritable protoplasm may be roughly compared to the action of the trigger upon a primed and loaded gun. It sets free forces vastly in excess of those which it exerts.

272. Reaction time.—The reaction does not follow instantly upon stimulation. The interval, which is known as the reaction time, is ordinarily much longer in plants than in the higher animals. In extreme cases no reaction may be manifest until several hours after stimulation. In other cases, however, as in the well-known sensitive plant, the movements of the leaves follow almost instantly upon stimulation.

273. Form of reaction.—The character of the reaction is not dependent upon the nature of the stimulus, but upon the nature of the organ itself. It is not in the least understood what the inherent peculiarities are which determine the form of the reaction. In different organs exactly opposite effects may be produced by the same stimulus, and the same organ at different ages may respond differently to the same stimulus. Thus the young internodes of the Virginia creeper (*Ampelopsis*) are sharply recurved, but become erect when older. The stalk bearing the flower of the peanut is erect, but as it becomes older it becomes strongly reflexed, and thrusts the fruit under ground.

274. Localization of irritability.—In multicellular plants irritability to certain stimuli is usually localized in certain organs, and often in special parts of these organs. In many tendrils, for example, the free end is curved and only the

concave side is irritable to contact. In the Venus' fly-trap, although the whole leaf moves at the contact, only the three hairs upon the upper face of each lobe are sensitive to a touch. (See figs. 386, 205.)

275. Transmission of stimuli.—In these cases, as in many others, the effect of the stimulus must be transmitted in some way from the point of application to the cells which produce movement. Much uncertainty exists as to how this is accomplished. In some cases it is doubtless done by means of the connecting threads of the protoplasm from cell to cell, after the analogy of a diffuse nerve. In other cases it may be transmitted through certain strands of tissue by the alteration of the hydrostatic pressure in the interior of the cells.

The movements of plants may be conveniently considered as (1) movements of locomotion by single cells; (2) movements of protoplasm within a cell-wall; or (3) mass movements of multicellular members of the higher plants.

I. Locomotion of single cells.

276. Naked cells.—Plants which consist of a single cell may be either naked or furnished with a cell wall. If naked, they may exhibit either *amœboid* or *ciliary* movements. Amœboid movements are slow creeping movements brought about by the protrusion of a portion of the protoplasm (a pseudopodium), toward which the remainder gradually flows (fig. 169). Ciliary movements are due to the extension of one or more very slender threads, called cilia, whose rapid bending in different directions propels the organism (fig. 168). According to the nature of the movements, the course will be zigzag or steady, accompanied by the rotation of the cell on its axis. When the cell comes to rest the cilia are either withdrawn or drop off.

277. Cells with a wall.—Movements of locomotion in plants possessed of a cell wall are either ciliary or creeping.

The latter are usually due to the protrusion of processes from the protoplasm through slits in the wall, as in many diatoms (fig. 20). The filaments of the water slimes bend from side to side, and so creep over wet surfaces very slowly (fig. 15). Bacteria (fig. 17) and some diatoms move by means of cilia.

II. Movement of protoplasm within a wall.

278. Streaming.—In multicellular organs it is common to find the protoplasm within each active cell moving about from point to point within the cell. The protoplasm is filled with numerous large vacuoles, so that it forms a layer next the wall, with threads or ribbons extending across it (fig. 188). When currents start along the wall and through the strands, the motion is designated as the streaming of the protoplasm. These currents along any particular portion of the protoplasm may run side by side and in opposite directions.

FIG. 188.—A single cell from a hair of *Chelidonium*. The arrows show the direction of movement of the protoplasm in the peripheral layer and in the bands which separate the vacuoles. *n*, the nucleus, with nucleolus. Highly magnified.—After Dippel.

279. Rotation.—When the protoplasm surrounds a single large vacuole and thus occupies only the periphery of the cell (fig. 181, *C*), the whole mass may rotate, usually in the direction of its long axis. The portion immediately in contact with the wall is motionless, and there must necessarily be a strip between the half moving up and the half moving down the cell, which is also quiet. Such movements are called rotation of the protoplasm. It is not known whether either streaming or rotation has any immediate relation to the well-being of the cell.

280. Cell organs.—In addition to the mass movements of the protoplasm, the smaller protoplasmic bodies

within the cell, such as the nucleus and the chloroplasts, are capable of moving about. Under moderate illumination chloroplasts accumulate upon the sides of the cells most directly reached by the light. Under very strong illumination they retreat to the walls least illuminated, or may even pile up in the angles of the cell so as to shade each other (fig. 189).

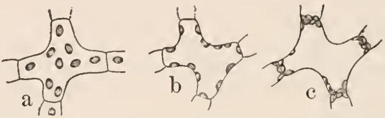


FIG. 189.—Cells from the spongy parenchyma of the leaf fo wood sorrel (*Oxalis*), seen from the direction in which light falls on the leaf. *a*, position of the chloroplasts in diffuse light; *b*, position after short exposure to direct sunlight; *c*, position after longer exposure. Highly magnified.—After Stahl.

III. Movements of multicellular members.

281. Forces.—The movements of multicellular parts may be brought about either by special organs known as motor organs, or by the growth of the immature parts. Motor organs are generally responsible for the movements of mature parts, while movements of the younger regions are generally due to growth. The force exerted by the motor organs is dependent upon the altered turgor of the cells of which the organ is composed. If the cells upon one side lose their turgidity, those upon the other, being unresisted, will extend and bend the organ toward the side upon which the turgor was diminished. It will be convenient, therefore, to distinguish movements due to growth and movements due to variation in turgor.

282. (A) **Movements of growth.**—These depend upon some inequality in the rate of growth of the organ concerned. They are of two sorts: (1) those in which variation in growth

is produced by internal causes, called spontaneous movements, and (2) those in which the variation in growth results from stimulation by external agents, called paratonic movements.

283. 1. **Spontaneous movements.**—Among spontaneous movements are those in which the variation in growth occurs upon different sides of a cylindrical organ, or the two faces of a bilateral one. The opening of all flower and leaf buds illustrates this movement, which is called *nutation*. During the development of the interior parts, the outer leaves (often scale-like) which protect them grow more rapidly upon their outer (dorsal) surfaces. They are thus pressed together into a compact bud. When the internal parts are suitably developed a change occurs in the rate of growth of the outer leaves; their inner (ventral) faces now grow more rapidly and the bud expands. Similar spontaneous variation in the growth of different sides of tendrils produces a nodding or waving motion, or even a rotation of the tip, by means of which they are often enabled to reach a support. In most tendrils the acceleration of growth travels irregularly around the axis, so that their tips rotate in a roughly circular or elliptical orbit from the time the tendril is two-thirds grown until growth ceases. The further changes in the tendril, by which it wraps the tip about the support and coils the remainder into a double spiral, are paratonic movements induced by contact. The rotating movements by which twining plants climb are also paratonic and not spontaneous.

284. 2. **Paratonic movements** are also of the highest importance for the well-being of the plants concerned. By means of them the different organs are developed in such situations that they can properly perform their work. The stimuli which influence the rate of growth are chiefly light, gravity, heat, mechanical contact, and moisture. The peculiar states in which a plant or an organ exists when it can respond to

the different stimuli have received different names, and those names indicate the nature of the stimulus. A plant or an organ is *heliotropic* when it reacts to the direction of the rays of light falling upon it; *geotropic*, when it reacts to the force of gravity; *thermotropic*, when it reacts to the presence of a warm body; *hydrotropic*, when it reacts to the presence of a moist surface, etc. In each case the plants are said to react *positively* when the movement is toward the source of the stimulus; *negatively*, when the movement is away from the stimulus; *transversely*, when it is transverse to the direction of the stimulus. These reactions are to a certain extent

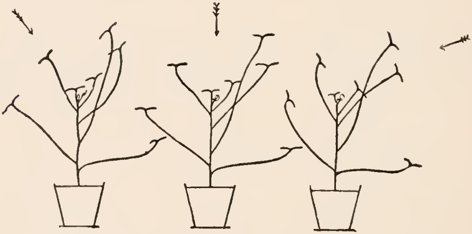


FIG. 190.—Diagrams representing the transverse heliotropism of leaves of the garden nasturtium (*Tropæolum*). Potted plants were subjected successively to light striking them in the direction shown by arrows. The petioles curved so as to place the blades at right angles to the incident light.—After Vöchting.

related to one another, and it will be convenient, therefore, to consider the effect of each stimulus upon the two common forms of plant organs—namely, the radial (such as stems and roots) and the dorsiventral (such as leaves). Organs are sometimes physiologically dorsiventral, even though they possess a radial structure; for example, some stems behave as dorsiventral organs, although they are perfectly radial in structure.

285. (*a*) **Heliotropism.**—Heliotropism is the state of a plant or organ when it is irritable to the *direction* of light rays.

Light thus plays an important part in determining the position of organs. As a rule radial organs are either positively heliotropic, as the stems and leaf-stalks, or negatively heliotropic, as the roots. Dorsiventral organs, such as leaves, are all transversely heliotropic, assuming a position at right angles to the incident rays, which is the most favorable position possible for the manufacture of food by the green parts (fig. 190). Intense light, however, may bring about a different reaction, so that the leaves set themselves edgewise to the

FIG. 191.—Leaf mosaic formed by a horizontal shoot of Norway maple. The lengthening of the petioles of individual leaves to avoid shading of the blade is marked. About one-third natural size.—After Kerner.

direction of the rays. A fixed light position is usually reached by leaves by the time they become mature, and this is generally at right angles to the source of greatest light. Branches of trees show the leaves so arranged as to size and position that they shade each other as little as possible, forming the so-called *leaf mosaics* (figs. 191 to 193). The leaves of window plants also exhibit these movements very strikingly,

because usually illuminated from one side. Plants kept in darkness have their leaves irregularly placed.

286. (*b*) **Combined movements** due to variations in the

Fig. 192.—A shoot of thorn-apple or "jimson" weed, showing imperfect leaf mosaics of tall plants formed upon the same plan as in rosettes (fig. 193). One-seventh natural size.—After Kerner.

amount of light or heat or both are especially exhibited by flowers, whose opening and closing are frequently determined

Fig. 193.—A rosette of leaves of a bellflower (*Campanula pusilla*), showing lengthening of petioles of lower leaves so as to carry blades from under upper leaves.—After Kerner.

thereby. With some plants the predominant stimulus is heat; with others, light. Closed flowers of the tulip or crocus may be made to open in 2 to 4 minutes by raising the temperature

15° to 20°. The flowers of the white water-lily (Nymphæa) and of the dandelion open in sunlight and close in shade. By marking upon their leaves a series of equidistant parallel lines with Chinese ink, and subsequently measuring the distances to which they have been spread, all such movements can be clearly shown to be due to accelerated growth of the outer or inner surfaces, respectively. The protection of the flower parts or the proper discharge of the functions is secured by these movements, which must not be confounded with those due to the *direction* of light or heat rays.

287. (*c*) **Geotropism.**—Geotropism is the state of a plant or an organ when it is irritable to the action of gravity. Since gravity is exerted always in the same direction, it is plain that reactions to this force cannot be studied, as in the case of light, by altering the absolute direction in which gravity acts, but only by so changing the position of the plant that the force acts in a relatively different direction. The reaction to this stimulus and the fixed gravity position must not be confused with the simpie effect produced by the weight of the parts concerned. Such effects are to be seen in the downward bending of some plants with slender branches, or the curvature of the flower or fruit stalks by the weight of the parts. True geotropic curvatures are brought about by acceleration of the growth of the irritable cells, and the curvatures produced may even be contrary to the direction of the force. If seedlings be grown in boxes upon the rim of a wheel rotating slowly in a vertical plane, so that they are successively subjected to the action of gravity in relatively different directions, it will be seen that while their members grow in nearly straight lines, the direction assumed by the stems and roots is quite as frequently abnormal as normal, because the effect of gravity which normally determines the direction of growth of these axes is neutralized, since it now acts upon them from a new direction at each

successive moment (fig. 194). If the wheel upon which such seedlings are grown be rotated at a high speed, the cen-

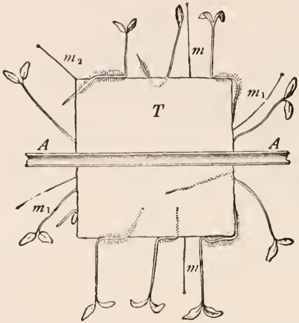


FIG. 194.—Seedling mustard plants grown on a cube of peat, *T*, attached to the slowly rotating axle, *A*, *A*, of a clinostat. The direction of growth of roots and stems is controlled only by the nearness of moist surfaces, the action of gravity and light being eliminated. Note the variable direction of roots and stems. At *m* and m_2 aerial hyphæ of a mold have taken direction as far from the repellant moist surfaces as possible. One half natural size.—After Sachs.

trifugal force will become a constant one, and, acting in place of the neutralized force of gravitation, will determine the direction which the stems and roots will assume. Since the primary stems of most plants are negatively geotropic, when grown under such conditions they will turn toward the center of the wheel, while the positively geotropic roots grow toward the rim. Similarly, if the wheel be rotated rapidly in a horizontal plane the stem will be controlled by a combination of the force of gravity and the centrifugal force (the latter predominating if the speed is great), and will grow inward and upward, while the roots will grow downward and outward (fig. 195).

288. Transverse geotropism.—Not all stems, however, are negatively geotropic, nor all roots positively geotropic.

The central axis of both root and stem in the majority of plants is so, but lateral branches of both place themselves at an angle to the action of gravity, sometimes at a right angle, at other times at a highly obtuse or acute angle. That is, they are more or less perfectly transversely geotropic. Whatever the normal position of any organ, it will be regained by the growing parts as rapidly as possible when the plant is forcibly displaced. This can only be brought about by the curvatures produced by unequal growth of the younger parts.

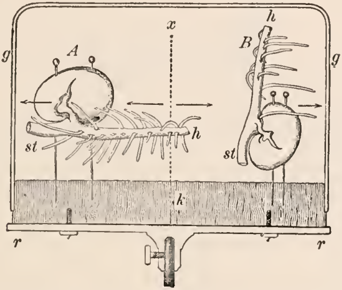


Fig. 195.—Part of centrifuge. *a*, the axle, rotated at a high speed by water or electric motor, to which is attached the circular metal plate, *r*, *r*, carrying a disk of cork, *k*. To the latter are attached two seedling beans, *A*, *B*, by means of pins; *st*, the primary stem; *h*, the primary root. Over the seedlings the cover, *g*, is placed to keep them moist. After a few hours the lateral roots have turned into the direction of the centrifugal force, which was sufficiently powerful to overcome that of gravity except near axis of rotation, *x*. One half natural size.—After Sachs.

If a potted plant be laid upon its side for a short time and then erected before any response to the stimulus occurs its growing parts still curve to one side, although not so far as if they had been allowed to remain in the horizontal position.

289. Grasses.—In only a few cases do the maturer parts of plants regain their power of growth under the stimulus of gravity. The basal portion of the internodes of grasses, however, remain for a long time capable of growth; hence,

when grasses are blown down or trampled their stems erect themselves by the geotropism of this basal growing zone (fig. 196).

Fig. 196.—Part of a wheat-stalk, showing strong geotropic curvature. The shoot was placed horizontal, and the growth of the basal part of the internode with the leaf-sheath connected with it was stimulated on the under side, the upper remaining short. No curvature occurs in the older part of the internode. About two thirds natural size. —After Pfeffer.

Fig. 197.—Root-cage. On the lower edge of a sheet of zinc a little larger than the panes of glass selected is formed a water-tight trough of the same material. Two panes of glass of suitable size are clamped together, with a piece of wood 1 cm. thick on three edges to keep them separate. Seeds are sown in fine soil evenly packed between the panes; these are set with the lower edge in the water-trough and a sheet of zinc is used to keep out light. The cage should be slightly inclined, as shown, so as to keep roots against the glass.—From a drawing by J. C. Arthur.

290. Root-cage.—Experiments upon the response of rootlets to the stimulus of gravity upon altering their position may be carried on by means of a root-cage, shown in figure 197. It consists essentially of two panes of glass placed close together, between which, in finely sifted soil, the rootlets are grown. By inclining this root-cage at various angles it may be shown that not only the primary root, but its branches, strive to regain their normal angle with the direction of gravity. This is illustrated in figure 198, in which the dark portion of the rootlets represents the growing parts while the cage was inverted. They then took about the same angle with the horizon as when in normal position.

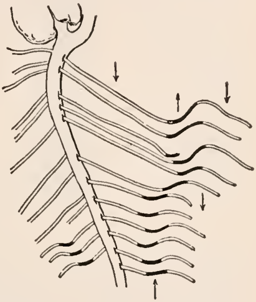


FIG. 198.—Part of the root system of a broad bean, grown in a root-cage, first in the normal, then in the inverted, and again in the normal position. The arrows show the direction in which gravity acted in the different positions. The black portion of the roots were the parts growing during inversion. Two thirds natural size.—After Sachs.

Many dorsiventral organs, such as leaves, are transversely geotropic, just as leaves are transversely heliotropic.

291. Twining plants.—The movements of twining plants are due to a peculiar reaction to gravity. As the upper internodes of a seedling elongate they soon become too weak to support themselves and bend over, becoming nearly horizontal. When this occurs the growth of the right or left flank of the stem near the bend is accelerated (whence the stem is said to be *laterally* geotropic). The horizontal part is thus swung around, twisting the stem and bringing a new flank under the influence of the stimulus. If in its continued rotation the stem comes in contact with a nearly erect support the free part continues to rotate, growing longer at the same time, and encircles the support. The part below the point

of contact now becomes negatively geotropic, and its growth on all sides is equally accelerated. The coils are thereby straightened until the stem clasps the support very closely, from which it is often prevented from slipping by angles or outgrowths of various kinds, which roughen the surface (fig. 199).

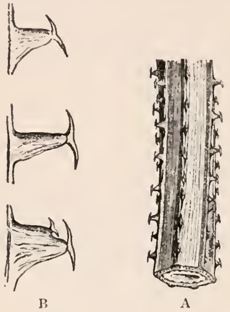


Fig. 199.—*A*, a bit of the stem of the hop, showing the six angles, each carrying a row of emergences, crowned by a branched rigid hair with very sharp points. Magnified 3 diam. *B*, three emergences more highly magnified.—After Kerner.

While gravity thus plays a large part in determining the position of both aerial and subterranean organs, it must be remembered that it works conjointly with many other stimuli. The position of the members is, therefore, a resultant of the reactions to the various external forces which stimulate it.

292. (*d*) **Hydrotropism.**—Hydrotropism is the state of a plant or an organ when it is irritable to moisture. Hydrotropic organs may bend toward or away from a moist surface. Roots are particularly sensitive to the presence of moisture. If a cylinder of wire gauze be filled with damp sawdust and a number of seeds planted near its surface they germinate and the roots start to grow in the normal direction—i. e., directly downward. If now the cylinder be suspended at an angle, as shown in figure 200, the roots which pass into the air, stimulated by the moisture, curve toward the damp sawdust. Upon entering it the stimulus ceases, and they start again to grow downward, being positively geotropic. Again the stimulus of the moist surface overcomes that of gravity, and they turn back to it, often threading themselves in and out

of the wire gauze. Since only one-sided action of a stimulus determines direction of movement, if the air be saturated they continue to react to the stimulus of gravity alone.

293. (*e*) **Movements due to contact.**—Contact, either gentle or forcible, and friction act as stimuli to modify the growth of many plant parts. Only rarely is the main axis of a plant sensitive to mechanical stimuli, except, perhaps, to long

FIG. 200.—Apparatus for demonstrating hydrotropism. *a*, *a*, a zinc disk, with hooks to which is attached a cylinder or trough of wire netting filled with damp sawdust. In this are planted peas, *g*, whose roots, *h*, *i*, *k*, *m*, first descend into the air but soon turn toward the damp sawdust again. *m* has threaded itself in and out of the netting.—After Sachs.

continued contact (or pressure) in the case of some twining plants. But in many plants lateral axes in the form of tendrils (¶¶ 115, 158) and leaf-stalks (¶ 157) are irritable to contact, even to a degree far surpassing that of our nerves of touch.

If the tip of a tendril (¶ 266), while still capable of growth, come in contact with a solid body, it will quickly become concave on the side touched, and thus will wrap about the object, if it be of suitable size. This curvature is due first to the shortening of the cells upon the concave side and later to unequal growth on opposite sides. Finally this effect

extends to all parts of the tendril, which begins to curve. As both ends are fast, it is a mechanical necessity that the curves become spiral coils, both right- and left-handed, accompanied by a twisting of the tendril on its axis (fig. 107). After the coils are formed the tissues of the tendril become thick-walled and rigid, so that the plant is attached to the support by a series of spiral springs.

Other tendrils do not nutate, but are negatively heliotropic, and by contact their tips are stimulated to develop disks which apply themselves closely to the support, and send into its irregularities short outgrowths from the surface cells. Such plants are adapted to support themselves by walls, tree-trunks, etc. The Japanese ivy and one form of the Virginia creeper are notable examples.

The coiling of the leaf-stalks is not unlike the first curvatures described for tendrils (fig. 154).

294. (B) Movements of turgor.—The movements just described are confined to members which are growing either throughout or in some part. As turgor can affect only tissues whose cell-walls are elastic (¶ 188), the movements produced directly by variation in turgor can occur in such mature members only as are provided with special motor organs. In almost all cases these are leaves. Stimuli which regulate growth (¶ 284) may also affect motor organs, producing like curvatures. But elongation of any part of a motor organ by increased turgor is reversible, not permanent, (cf. ¶ 254).

295. Motor organs.—The motor organ in leaves is usually the leaf base (¶ 151) or a modified portion of the petiole, sometimes greater but generally less in diameter than the rest. Its cortex consists of large, rather thick-walled, parenchyma cells, and the stele occupies a relatively small part of the transverse section. In other parts of the petiole the stele is much larger, or there may be several steles distributed

about the center. (See ¶ 164.) In figure 201, *A* and *B* show the contrast. If the leaf be a compound one, there are usually secondary motor organs at the base of the leaflets, as in the leaf of the bean (fig. 202). Variation in the turgor of the cells of the cortex upon one side or the other produces a sharp curvature of

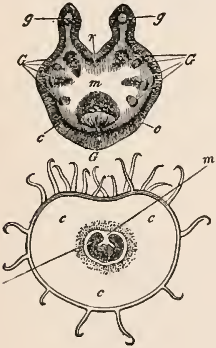


Fig. 201.

Fig. 202.

Fig. 201. —Transverse sections through petiole of scarlet runner. *A*, through the rigid portion; *B*, through the motor organ. *G*, *g*, vascular bundles; *c*, cortex; *m*, pith; *r*, deep channel along ventral side of petiole. Magnified about 10 diam.—After Sachs.

Fig. 202.—Portion of a scarlet runner, which, originally growing erect, has been inverted for several hours, resulting in geotropic curvatures of the primary motor organs *P*, P^1, P^2. The lowest pair of leaves show secondary motor organs at the juncture of petiole and blade. Similar ones are present in the upper compound leaves, but are not clearly shown in the figure. The arrows show the position of the petioles when the plant was first inverted. About two thirds natural size.—After Sachs.

the motor organ, which alters the position of the leaf or leaflet (fig. 202). The concave surface of the motor organ is always deeply wrinkled transversely, while the convex surface is smooth.

296. Spontaneous movements.—Only a few plants exhibit spontaneous movements through the motor organs. The lateral leaflets of the telegraph plant (*s*, fig. 203), under normal conditions of rather high temperature (at least 22° C.), show jerky movements of such direction that their tips describe an irregular ellipse, which is completed in 1 to 3 minutes. The leaflets of the clovers and oxalis show much slower movements (of a few hours period), which are usually obscured by the light movements described in the next paragraph.

FIG. 203.—Leaf of *Desmodium gyrans*. Two thirds natural size.—After Sachs.

More commonly the turgor movements are induced. The most common stimuli are light and contact, although many others suffice to induce them.

297. Photeolic movements.—Movements produced by the withdrawal of light have long been known as "sleep movements;" more properly, photeolic movements—that is, movements induced by variation of light. They are best observed upon the leaves of the bean family, though many other plants exhibit them. Figure 204 shows the positions assumed by various leaves toward nightfall. It will be seen that in compound leaves the leaflets sometimes rise, so as to apply their outer faces to each other; others sink, so that the under surfaces are in contact; others become folded in various ways. This position is maintained throughout the night. Upon the increase of light in the morning, the day position is assumed. The cutting off of light artificially from any of these plants causes them within a short time to assume the nocturnal position. Darwin suggested that the nocturnal position prevents the loss of heat by radiation and consequent injury from light frosts. But it is not by any means certain that this is its real purpose.

298. Contact movements.—Some organs are sensitive to contact, as the leaves of Venus' fly-trap and other related plants. The motor organ in the Venus' fly-trap (figs. 386, 205) is the cushion of tissue running along the dorsal side of the leaf between the two lobes. By the sudden variation in

FIG. 204.—Photeolic movements. *a*, leaf of a mimosa in day position; *a'*, the same in night position. *b*, leaf of *Coronilla varia* in day position; *b'*, the same in night position. *c*, leaf of *Amorpha fruticosa* in day position; *c'*, the same in night position. *d*, leaf of *Tetragonolobus* in day position; *d'*, same in night position.—After Kerner.

turgor of some of these cells the two halves of the leaf are thrown quickly together when one of the six bristles upon its upper surface is touched. The sensitive plant drops one of its leaflets or the whole leaf quickly when stimulated by contact, heat, or electricity. The position of the leaves when

normally expanded is shown in figure 206, and their position after stimulation by figure 207. The stamens (¶ 344) of some flowers and the stigmas (¶ 336) of others are sensitive

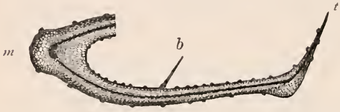


FIG 205.

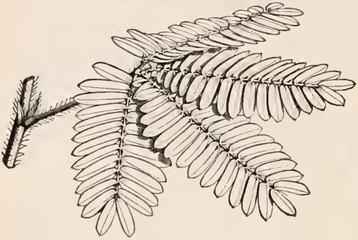


FIG. 206.

FIG. 207.

FIG. 205.—Part of a transverse section of a leaf of Venus' fly-trap. *m*, the cushion of tissue constituting the motor organ; *b*, one of the sensitive bristles which, upon being touched, cause the leaf to close; *t*, one of the interlocking teeth. The minute projections over inner (ventral) surface are glands which secrete the digestive fluid and later absorb the food. Magnified about 5 diam.—After Kurz.

FIG. 206.—A leaf of the sensitive plant fully expanded. Natural size.—After Duchartre.

FIG. 207.—A leaf of the sensitive plant after stimulation. The motor organ at the base of each leaflet has thrown it forward and upward; the motor organs at the base of the four divisions have moved them together. The motor organ at the base of the main petiole has moved the whole leaf sharply downward. Natural size.—After Duchartre.

to a touch, shortening, elongating, or bending in such a way as to promote pollination (¶ 358).

The motor organs of the leaves of a number of the bean and oxalis families also react to more violent mechanical stimuli. Their movements are similar to those described in ¶ 297.

PART III: REPRODUCTION.

CHAPTER XVI.

INTRODUCTION.

Having considered in Parts I and II the structures and functions by which the nutrition of the individual is secured, Part III is devoted to the consideration of the structure and functions of the reproductive organs and the functions by which a succession of similar individuals is insured.

One of the fundamental powers of protoplasm is its ability to produce new organisms as offspring from the older ones. In the simpler plants the two great functions, nutrition and reproduction, are often carried on by the same cell. This must always be so in the unicellular plants. In the higher plants, however, these two functions become completely separated, organs being specialized for each, so that the functions may be more certainly and efficiently performed.

299. Reproductive structures.—Any part capable of growing into a new individual may be called a *reproductive body*, and the part on which or in which it is produced is a *reproductive organ*. If the reproductive bodies consist of one or two cells only, they are usually called *spores*. If they are cell-aggregates, they are generally called *brood buds* or *gemmæ*, to distinguish them from ordinary buds. In both cases it is necessary that the cells to be separated from the parent should be capable of growth—that is, in the condition known as the embryonic phase (¶ 256). The reproductive organs pro-

duced by some plants are exceedingly complex and varied, while others form reproductive bodies in very direct ways. The reproductive bodies themselves are generally very simple. In addition to complex reproductive organs, there are sometimes accessory parts by which the plant adapts its reproductive functions to the conditions under which it lives. Among these accessory structures are many, as among the flowers of seed plants, by which the aid of other plants or animals is secured.

300. Vegetative and sexual reproduction.—In all the diversity of organs and processes two chief methods may be distinguished, called *vegetative reproduction* and *sexual reproduction*.

Vegetative reproduction consists in the formation of reproductive bodies by processes of growth only. The modes in which they arise are varied in detail, but consist essentially in the production by the parent of a body, unicellular or multicellular, which at maturity develops, under suitable conditions, into a new plant.

Sexual reproduction consists in the formation of reproductive bodies by the union of two specialized cells, neither of which alone is capable of developing into a new plant.

CHAPTER XVII.

VEGETATIVE REPRODUCTION.

I. Fission and budding.

301. Fission.—In single-celled plants cell division and reproduction are practically identical, since shortly after division occurs the two cells so produced separate and lead an independent existence (*C*, fig. 18). Such a method of reproduction evidently interferes little with the processes of nutrition, which probably are scarcely even suspended during the process of reproduction.

302. Budding.—A slight variation of the method of fission just described is to be found in those single-celled plants, such as the yeasts, whose growth is so localized as to form upon one side a small enlargement which ultimately attains the size of the parent, with which it is connected by a very narrow neck (fig. 48). Across this neck the partition wall is formed in the usual way. This becomes mucilaginous, rendering the adhesion of the daughter cell at this point so weak that it is easily separated from the parent. This method of reproduction is known as *budding*.

303. Fragmentation.—In those plants which consist of a row of cells more or less closely united, the breaking up of the filaments into separate pieces, either through external force or the death of one of the cells, may produce a number of smaller colonies or of new individuals, each of which may grow to full size. In some of the more loosely organized filament-colonies, such as Nostoc (see ¶ 13, and figs. 13, 14), there are specialized cells whose function seems to be

to loosen pieces of definite length, which creep out of the jelly, grow, and thus produce new colonies.

The greater size reached by most multicellular plants soon renders impossible the continuance of this method of reproduction, except among those whose cells are all alike. Should such separation into nearly equal parts occur among more highly specialized plants, it is evident that one portion might easily be left without nutritive organs adapted to its needs. The higher plants, therefore, specialize certain regions or members, where, by division or budding or similar processes, reproductive bodies may be formed.

II. Spores.

304. Sexual and non-sexual spores.—A spore is a single-celled body capable of producing a new plant. Spores may be formed either by a process of growth or by a sexual act—i.e., the union of two cells. The former are called non-sexual spores; the latter, sexual spores. Only non-sexual spores are discussed in this chapter.

305. Structure.—While a spore is generally composed of one cell, the term is extended to include two- to many-celled bodies which are formed in the same way as the simpler ones. In fact, no clear distinction in form or structure can be drawn between spores and brood-buds. (See ¶ 361.)

306. Motile spores.—Spores may be either naked and motile or furnished with a cell-membrane and non-motile. The former are commonly produced by plants which pass all or part of their lives in water, such as the algæ and aquatic fungi. They are usually pear-shaped and furnished with one or more cilia, by means of which they swim about (fig. 168). When locomotion was supposed to be a distinctive power of animal bodies they were called *zoospores*, a name still retained. They are also called swarm-spores.

When zoospores possess chlorophyll-bodies, as they frequently do, they are aggregated at the larger end, leaving the pointed end to which the cilia are attached colorless. Zoospores are formed either in a general body-cell, not visibly different from the other body-cells, or in a cell specialized in form and structure. In either case the cell in which they are produced is called a zoosporangium. The entire contents of the zoosporangium may form a single zoospore, or it may divide into several or many. In the latter case the nucleus divides into two or more, each of which gathers about itself a portion of the protoplasm. The zoospores are set free by the rupture of the wall of the sporangium or by the solution of a portion of the wall (fig. 208). They may begin to move before the rupture of the wall, in accomplishing which their activity may materially assist. They then work their way out and swim freely in the water. After a time of movement they usually lose their cilia, either withdrawing them into the protoplasm or dropping them off, come to rest, and begin to grow into a new plant.

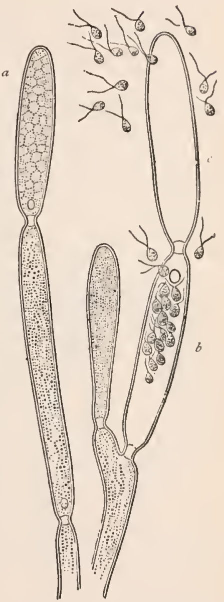


FIG. 208.—Development and escape of zoospores of an aquatic fungus (*Saprolegnia lactea*). The ends of two hyphæ are shown, the terminal cells being zoosporangia. In *a*, the protoplasm is aggregating about the numerous nuclei (not shown). From *b* many of the zoospores have escaped through the perforation in the wall near the upper end of the cell. From *c* all have escaped but one, which is just slipping through the opening (here in profile). Magnified 300 diam.—After Kerner.

307. Non-motile spores are formed by all classes of land plants without exception. They

are often produced in great profusion, especially by the fungi, the mosses, the ferns, and the seed plants.

308. Form and structure.—Their form is exceedingly various. Many are spherical or ovoid, while some are cylindrical or even needle-shaped (figs. 213, 228, 271). Irregular forms, also, are not uncommon.

In structure spores are usually only single cells, specialized. Each is a nucleated mass of protoplasm surrounded by a cell-wall which may be either thin or thick, according as the spore is destined to immediate growth, or, as a resting spore, to endure for a time unfavorable conditions.

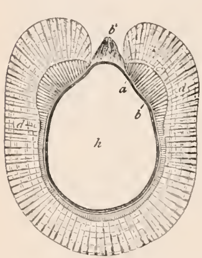


FIG. 209.—Section of a mature spore of *Pilularia globulifera*. *h*, the cavity of the cell (contents not shown); *a*, the true wall; *b* the first, *c* the second, *d* the third layer of the epispore. *b* forms a papilla at *b'*. *c* and *d* have a prismatic structure. Magnified about 50 diam.—After Sachs.

In some cases the wall of even the thin-walled spores has two layers, a condition which is almost universal among resting spores. When the wall is so differentiated the inner layer is delicate, rarely thickened, extensible, and composed of more or less unaltered cellulose. The outer layer is often irregularly thickened, so that its surface is covered with ridges, warts, spines, or bosses of various sorts (figs. 210, 248, 271, 399). It is brittle, as compared with the inner coat, and is usually more or less altered in composition from its original cellulose nature. A third layer (the *epispore*) is sometimes present, but this is not produced by the cell which it surrounds. It is added from the outside, being derived from the protoplasm surrounding the spores after they are formed* (fig. 209). This form of spore is common among the fern allies.

* This protoplasm often comes from the disorganization of some of the cells around the chamber in which the spores lie.

309. Food.—In almost all cases there is a supply of reserve food within the spore. This reserve food varies in amount with the conditions under which the spores are formed. It is ordinarily greater in resting spores than in those intended for immediate growth. Spores may contain chlorophyll, but generally do not; even the spores of green plants are mostly without it. Its presence seems to indicate an active condition of the protoplasm, and the vitality of such spores is usually of short duration. It is of course absent from the spores of colorless plants, such as the fungi.

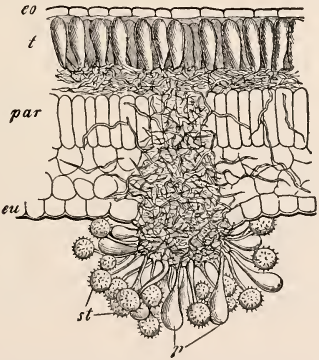


FIG. 210.—Part of a vertical section of a leaf of a willow, attacked by a fungus (*Melampsora salicina*). *eo*, epidermis of upper side lifted by the young teleuto spores; *t*, developing from the spore-bed above the ends of the palisade parenchyma, *par*; *eu*, epidermis of the under side, broken through spore-bed from which spring uredospores, *st*, and paraphyses, *p*. *eo* will also finally be ruptured to set free *t*. Magnified 260 diam.—After Prantl.

310. Growth.—Spores germinate by absorbing water, thus bursting the more rigid layer or layers of the cell-wall. The inner layer then grows in area to accommodate the increasing protoplasm, which so controls the regions of growth and the mode of cell division as to produce a plant of definite

form. In many cases the plant produced is essentially like that which gave rise to the spore. In others it is different, but sooner or later in the life cycle the same form recurs. Variety of bodily form is common among the fungi, in which it is called *pleomorphism*. Among plants showing well-defined alternation of generations (¶¶ 55, 320), the non-sexual spores are produced by one form only, and always give rise to the other.

311. Origin.—Non-motile spores are either *free*, being produced at the ends of branches specialized for that purpose, or enclosed in a case called a *sporangium*. Often the same plant forms spores by both methods at different stages in its development.

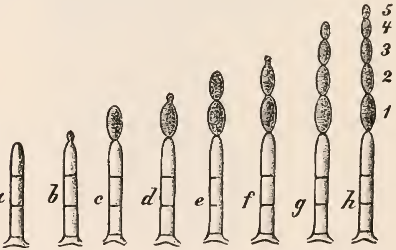


Fig. 211.—Diagrams showing the formation of an acropetal spore-chain by budding. *a*, the spore-producing hypha; *b*, its terminal cell showing a bud which in *c* has matured into a spore; *d*, the spore *c* has budded, and so on, until in *h* five spores have been formed, numbered in order of their development.—After Zopf.

312. Free spores.—The formation of free spores is confined to the lower plants, and is especially characteristic of the non-aquatic fungi. The branches producing spores may occur singly, or, more commonly, they are aggregated at certain points, forming a spore-bed (fig. 210). If the fungus develops its mycelium in the interior of a host, the formation of a spore-bed is often necessary to rupture the host, so that

the spores may be brought to the surface and set free. Thus the spore-beds of parasitic fungi commonly blister the surface of the host by lifting up its outer tissues (*eo*, fig. 210).

313. Spore-chains.—Spores may be produced either singly at the ends of the branches or in chains. When produced in chains, the youngest spore may be at the base or at the apex of the chain. The first method is much more common than the second. In the second case each spore must arise as a bud upon an older spore, budding itself to form a younger one (fig. 211). The spores in such a chain are limited in number. They develop rapidly, and all are loosened at about the same time. Those chains which have the oldest spore at the apex

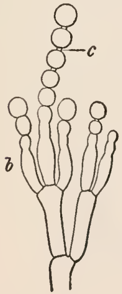


FIG. 212.

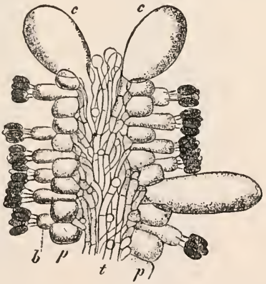


FIG. 213.

FIG. 212.—An outline showing the formation of a basipetal spore-chain of the blue-green mold (*Penicillium glaucum*). *b*, branch of spore-bearing hypha, budding beneath two older spores. Across the narrow neck a partition wall is formed, the spores round off, and from this wall a device, *c*, for loosening the spores is developed. The terminal spore is oldest. Highly magnified.—After Frank.

FIG. 213.—Longitudinal section through the edge of a gill of a mushroom (*Coprinus*) after spore-formation is completed. *t*, interwoven hyphæ of the gill, branching to form the hymenium, composed of the paraphyses, *p*, the cystidia, *c*, and the basidia, *b*. The latter give rise to four slender branches, whose tips enlarge to form each a single spore. *p* and *c* do not produce spores. Magnified 300 diam.—After Brefeld.

are produced by the continued division of the branch by transverse partitions, usually preceded by budding of the apex, often described as constriction (*b*, fig. 212). Beneath

the first spore so formed another spore is produced as the first grows older; and this process continues as long as the plant is able to furnish material for the making of spores. In such cases, often the oldest spores are liberated while new ones are being produced at the base of the chain.

A modification of the production of spores singly occurs when the branch destined to produce them gives rise to two to eight very slender branches, each of which enlarges at the tip into a single spore, so that the main branch appears to carry two to eight spores upon slender stalks. Such a spore-producing branch is called a basidium (fig. 213). It is the characteristic form in the higher fungi, which produce conspicuous fructifications.

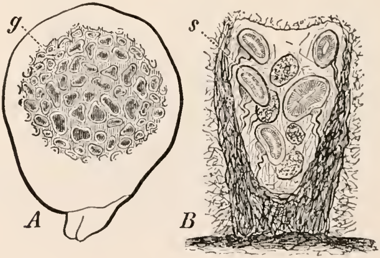


FIG. 214.—*A*, a puffball (*Octaviana*) halved, showing the internal chambers (shaded dark) lined by hymenium (the narrow white border). The intervening spaces, *g*, and the unshaded outer part are formed of interwoven hyphæ. Magnified 5 diam. *B*, a bird's-nest fungus (*Crucibulum*) halved. The similar internal chambers have been loosened by the disappearance of the intervening hyphæ immediately about the hymenium (represented by radiating lines) and a wavy stalk by which each remains loosely attached. Magnified 4 diam.—After Luerssen.

314. Fructifications.—In the higher fungi whose mycelium is developed within a dead substratum many branches are aggregated to constitute a reproductive structure or fructification, which is the only conspicuous part of the fungus. (For an account of the vegetative parts, see ¶¶ 50, 54.)

The body of the fructification is made up of hyphæ, more or less interlaced and adherent, and is of a form adapted, not only to break through the substratum, but also to furnish an extensive surface for the spore-beds, called in these plants the *hymenium* (fig. 213). The hymenium consists of the enlarged

FIG. 215.

FIG. 215.—A fructification of *Clavaria aurea*. The hymenium covers the upper part of the branches. Natural size.—After Kerner.

FIG. 216.

FIG. 216.—A fructification of a mushroom, *Amanita phalloides*. *p*, the cap or pileus; *v*, the veil, originally connected with edge of cap, covering the gills which radiate from the stipe, *st*, to the edge of cap; *vo*, the volva. The surface of the gills is covered with the hymenium. Most mushrooms showing a distinct volva are poisonous. Natural size.—After Kerner.

free ends of the hyphæ, which are set at right angles to the surface. Some, the basidia, develop 2–8 slender branches each of which produces at the tip a single spore. The hymenium may be formed upon the outer surface of the fructification or in internal chambers (fig. 214). In the latter case

these chambers rupture at the maturity of the spores, or even earlier.

The fructification may be irregularly lobed, sessile and gelatinous, or much branched and cylindrical or flattened,

FIG. 217.—Fructification of *Hydnum imbricatum*. The surface of the projecting spines on the under side of the cap are covered with the hymenium. Natural size.—After Kerner.

FIG. 218.—Trunk of an ash tree, showing fructifications of *Polyporus ignarius*. After a photograph by Von Tubeuf.

with the hymenium covering the whole or the upper part of the body, as in *Clavaria* (fig. 215); or it may form an umbrella-like, stalked cap, as in toadstools, with the hymenium extending over radiating plates on the under side of the cap, as in *Agaricus* (fig. 216), or over spine-like projections in the same region, as in *Hydnum* (fig. 217); or it may be a semicircular, sessile body projecting from the substratum like a shelf or bracket, with the hymenium lining innumerable minute

tubes on the under face, as in *Polyporus* (fig. 218); or it may take the form of a ball, the hymenium arising as a lining upon the walls of regular or irregular internal chambers, which may occupy most of the interior, as in puffballs and their kin (figs. 214, 219).

315. Sporangia.—Spores are also formed in the interior of cells which are either free or covered by a jacket of other

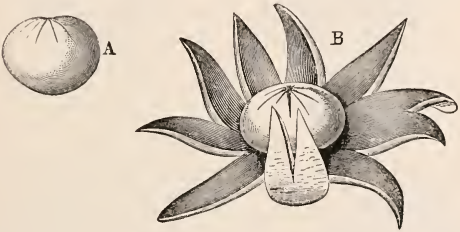


FIG. 219.—Fructification of a puffball (*Geaster hygrometricus*); *A*, young; *B*, mature, the outer layer split open and recurved, the inner also broken to allow escape of spores. Natural size.—After Corda.

cells. The entire structure is called a sporangium. In the first case the sporangium is said to be *simple*. Its wall is the wall of the mother cell in which the spores are produced, and they are set free by its rupture (fig. 220). In the second case the sporangium is said to be *compound*. The mother cells of the spores (rarely only one mother cell) are surrounded by others forming a jacket of greater or less thickness. In the mother cells, which are differentiated from the investing cells, the spores are formed as in simple sporangia. As the spores mature the walls of the mother cells burst or are disorganized, leaving the spores still surrounded by the layer or layers of investing cells (fig. 221). This jacket is ruptured sooner or later and the spores, thus set free, are distributed in various ways. (See ¶ 475.)

316. Simple sporangia.—The simple sporangium may be like the general body-cells, or it may be specialized in

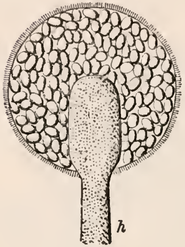


Fig. 220.

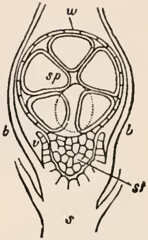


Fig. 221.

Fig. 220.—Longitudinal section of the simple sporangium of a mold (*Mucor*). The aerial hypha, *h*, has partitioned off a cell, *s*, within which spores are produced. The walls of this sporangium are studded with needle crystals of calcium oxalate. The partition protrudes far into the end cell. Magnified 260 diam.—After Kerner.

Fig. 221.—Longitudinal section of the stem, *s*, of a moss gametophyte, bearing leaves, *b*. Embedded in the stem is the sporophyte, consisting of a stalk, *st*, and a compound sporangium, of which *w* is the wall, formed of a sheet of cells, enclosing the spores, *sp* (contents not shown). Magnified 100 diam.—After Hofmeister.

form as well as in function. It may be spherical, sac-like, or linear. The elongated sporangium produced by the enlargement of the end of a hypha in certain fungi has received a special name, *ascus*. The number of spores formed within a simple sporangium may be two or more, up to several hundred. The spores are formed like the zoospores described in ¶ 306, with the difference that a wall is secreted by each spore *before* it escapes.

The rupture of the cell-wall, which sets the spores free, is brought about by the increase of the spores in size, or by the swelling of the surplus protoplasm left after their formation. Preparatory to bursting, the wall is frequently altered so as to be mucilaginous, or it becomes brittle. In some cases a certain area is thin, which furnishes a starting-point for the rupture.

317. Arrangement.—Simple sporangia may occur singly or they may be aggregated. When aggregated, they usually stand side by side, and constitute a layer, called the *hymenium* (figs. 222, 226). (Compare ¶ 314.) When thus aggregated (and even when single) they may be enclosed by a jacket formed by the coalescence of sterile filaments, as in the mildews, in which the whole structure constitutes a fructification (figs. 223, 224, 337). In the lichens the hymenium, during its earlier stages, is partially enveloped by sterile filaments forming a cup-like *apothecium* (figs. 225, 226). In the cup fungi (fig. 222) the fructification, which is the only part of the fungus above the substratum, is a single apothecium, whose whole inner face is the hymenium. In an allied form, the morels (fig. 227), the fructification is differentiated into a stalk carrying an enlarged head marked by narrow ridges separating broad shallow pits. The hymenium extends over the surface of these depressed areas. In other fungi, the sporangia are sunk in deep, narrow-mouthed pits with which the outer part of the fructification is filled (fig. 228).

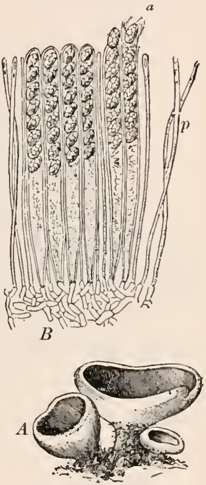


FIG. 222.—A cup fungus (*Peziza aurantia*). *A*, three fructifications, about natural size. The inner surface of the cup is covered with a hymenium, a bit of which is shown at *B* in section at right angles to surface. *p*, paraphyses; *a*, an ascus bursting to allow escape of spores. Highly magnified.—After Kerner.

The simple sporangia of some of the red seaweeds show a transition to the compound type in being formed by an internal cell of the thallus (fig. 229). The adjacent cells, however, do not constitute a special wall, nor are they neces-

sarily ruptured to permit the escape of the spores, being often displaced in the development of the sporangium, so that at maturity it is partially free.

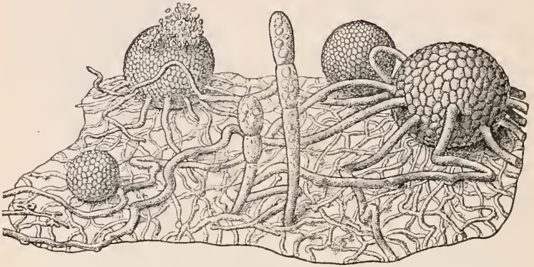


FIG. 223.—A mildew (*Erysiphe communis*), showing the mycelium ramifying over a bit of leaf, with erect spore-bearing branches and globular fructifications, containing asci. Magnified about 175 diam.—After Tulasne.

318. Compound sporangia.—Simple sporangia occur only among the lower plants. In the higher plants, including the mossworts, fernworts, and seed plants, the sporangium is always compound.

FIG. 224.—A cluster of asci from the interior of the fructification of a mildew (*Erysiphe Heraclei*) similar to those shown in fig. 223. Each ascus contains four spores. Magnified 200 diam.—After De-Bary.

319. Development. — Compound sporangia may be developed either from superficial or from internal cells. As a consequence, the mature sporangia will be either free or more or less enclosed within the tissues of the organ by which they are borne. A superficial cell may enlarge so as to protrude from the surface, and divide into two parts, of which the upper cell develops into the sporangium proper, and the lower cell into its stalk. According to this method of development the sporangium is a surface appendage, and may be looked upon

as homologous with a hair. Sometimes the sporangia, although really free, are overgrown by adjacent parts, so that

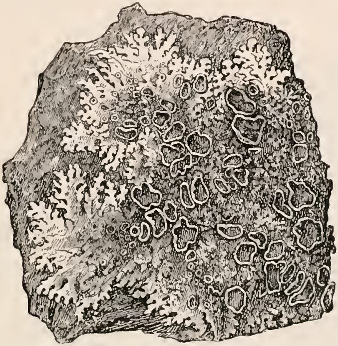


FIG. 225.—A lichen (*Parmelia conspersa*) growing on a stone, showing the leaf-like thallus (mycelium), with many fructifications (apothecia). The older ones are more or less irregular and large with a narrow rim; the younger are nearer the margin, circular, and nearly closed over at top. Natural size.—After Frank.

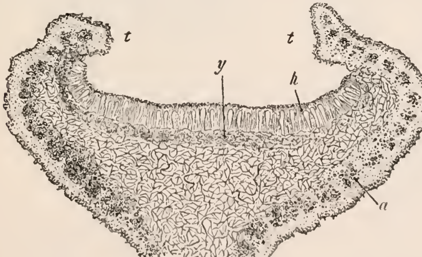


FIG. 226.—A vertical section of an apothecium of a lichen (*Anaptychia ciliaris*). *h*, the hymenium; *y*, the subhymenium, a layer of densely interwoven hyphæ; *t*, *t*, the sterile hyphæ which partially enclose the hymenium; *m*, the loosely woven hyphæ of the thallus; *a*, the algæ enslaved by the fungus. Magnified about 50 diam.—After Sachs.

they are enclosed in a chamber, whence the spores escape after they are set free by the bursting of the sporangium.

The other mode of development produces enclosed sporangia. One or more internal cells differentiate and become the mother cells of the spores. The spores, when mature,

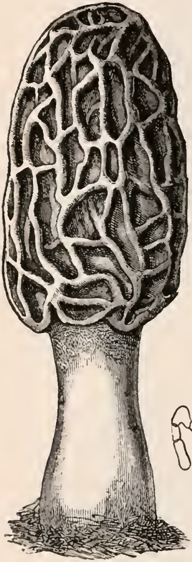


Fig. 227.

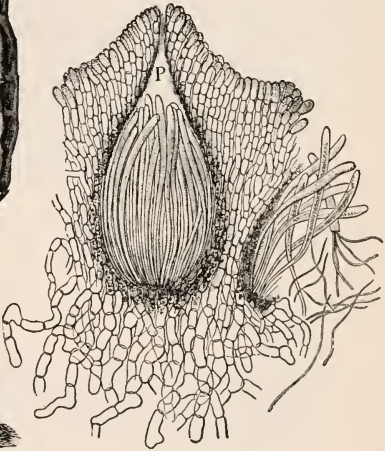


Fig. 228.

Fig. 227.—A fructification of the morel (*Morchella esculenta*). The hymenium occupies the surface of the depressed areas. Natural size.—After Kerner.
Fig. 228.—A small bit of a section through the fructification of the ergot (*Claviceps purpurea*), showing one of the deep, narrow-mouthed pits, *P* (and part of another), enclosing the asci. From the broken ascus at the right thread-like spores are escaping. Highly magnified.—After Tulasne.

will therefore be enclosed by the adjacent cells of the plant, which may became altered so as to form a sort of special wall more or less different from the tissue which lies farther off.

320. The sporophyte.—Among the mossworts, fernworts, and seed plants reproduction by non-sexual spores has become so fixed and important that one stage in the plant is devoted especially to producing them. This phase is different from that producing sexual cells, the difference becoming greater the more complex the plant. The stage set apart for spore production is called the sporophyte. In the mossworts the sporophyte has very little green tissue, and therefore carries on little nutritive work, but depends for its supply of food chiefly upon the sexual stage, with which it is connected throughout its entire existence (¶ 68). In the fernworts and seed plants, however, the sporophyte possesses extensive nutritive tissues, the leaves, stems, and roots belonging entirely to this stage. Sporangia in these plants may be formed either upon the stem or the leaves—never upon the roots.

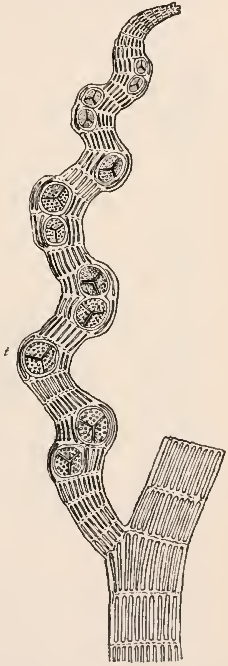


FIG. 229.—A branch of a red seaweed (*Polysiphonia opaca*), showing tetraspores, *t*, formed by an internal cell of the thallus. Magnified about 100 diam.—After Kützing.

321. Liverworts. — In the liverworts the sporangium is generally produced at the upper end of a short or long stalk. It is either spherical, ovoid, or short-cylindrical (figs. 64, 65). The spore-producing tissue occupies the greater part of the interior, the wall being formed usually by a single layer of

cells. Mixed with the spore-producing cells, however, are many sterile cells, which become gradually elongated, and

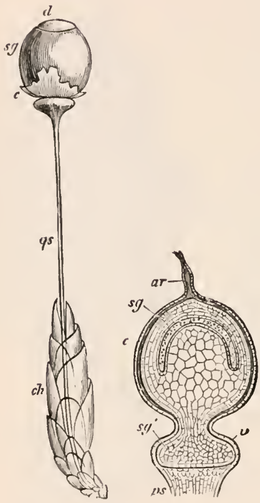


Fig. 230.

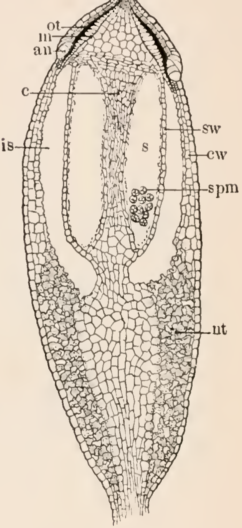


Fig. 231.

Fig. 230.—The sporophyte of a peat moss (*Sphagnum acutifolium*) with adjacent parts of the gametophyte. The sporophyte consists of a capsule, *sg*, and a broad foot, *sg'*. At the stage shown in *B* it is still completely enclosed in the tissues of the gametophyte, viz., *c*, the enlarged ovary which forms the calyptra or hood, and *v*, the vaginule or sheath surrounding the foot. *ar* is the neck of the ovary. (Compare fig. 331.) The arc over the large-celled central tissue (columella) is the sporangium. *ps*, the false stalk, produced by the gametophyte, which raises the sporophyte. In *A*, the calyptra has broken, only a fragment remaining, exposing the capsule. *d*, the lid, by whose fall the sporangium is exposed and the spores escape. *ch*, leaves of the gametophyte; *qs*, the false stalk. Compare figs. 67, 72, 73, in which the stalk is part of the sporophyte. *A* magnified 13 diam.; *B*, 32 diam.—After Schimper.

Fig. 231.—Longitudinal section of the young capsule of a true moss (*Bryum*). *s*, sporangium. At this stage the mother cells of the spores, *spm*, have become free (only a few are shown still enclosing the spores); *sw*, the wall of the sporangium, lined by the remains of another layer of cells now disorganized; *c*, the columella, of partly collapsed cells; *is*, intercellular space; *cw*, wall of the capsule; *an*, the annulus, a ring of cells which pries off the lid, at whose edge they develop; *ot*, the outer, *m*, the inner, peristome, formed by the thickening of parts of the walls of certain rows of cells; *nt*, nutritive tissue, with chloroplasts and intercellular spaces. Magnified 25 diam.—Original.

in many species thicken their walls along one or more spiral lines. These sterile cells are called *elaters* (fig. 11, *A*, *A'*). They serve to entangle the spores in clusters when they are set free. The sporangium opens at maturity by splitting at the apex, sometimes into two, commonly into four or more, parts (fig. 64).

322. Mosses.—In most mosses the sporangium is developed within the enlarged upper part of the sporophyte, to which the name capsule is given. In the peat mosses it is cap- or thimble-shaped (fig. 230), while in most of the true mosses it is a hollow cylinder (fig. 231). It opens by the falling off of the sterile upper end of the capsule, which separates as a lid and thus allows the spores to escape from the upper end of the cylindrical sporangium. By the time the spores are mature, the sterile central tissue of the capsule, which forms the columella (*c*, fig. 231), shrivels and often almost disappears, so that the capsule seems to be a cup or urn, filled with loose spores. In the younger stage (fig. 232) the original form is shown.

323. Ferns.—In the ferns the sporangia are usually numerous, stalked, free, and often associated in clusters called sori. They are either produced upon the under surface of the foliage leaves or upon specialized leaves.* The sori are often arranged in elongated clusters or lines (fig. 233). Each sorus, or a cluster of them, may be protected by a special outgrowth from the cells in its neighborhood, called an indusium (figs. 233, 234). Each sporangium consists of a stalk composed of two or four rows of cells expanding above into a body composed of a single outer layer enclosing the spore-producing cells, and at maturity the spores themselves. The walls of a row of cells more or less completely encircling the body of the sporangium become

* It must be remembered that the entire plant, consisting of root, stem, and leaves, is the homologue of the capsule and stalk of the mossworts.

irregularly thickened (see fig. 401). The strains caused by the unequal absorption and loss of water burst the sporangium at some definite point. This line of dehiscence is often between a pair of large saddle-shaped cells (fig. 401).

324. Sporophylls. — In many of the ferns the leaves which produce sporangia are not different from the foliage leaves. In others, certain leaves are so specialized for bearing the sporangia that they lose their nutritive function in part or entirely. To such specialized leaves the name *sporophyll* is applied.

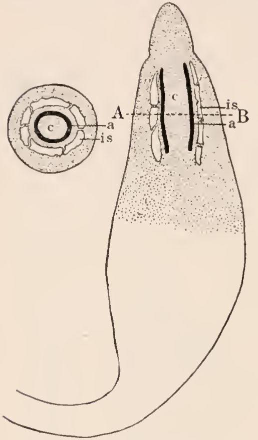


Fig. 232.

Fig. 233.

Fig. 232.—Diagram of a longitudinal and transverse section of the very young capsule of a true moss (*Bryum*). The transverse section is taken along the line *AB*. *a*, the mother cells of the spores; *c*, the columella; *is*, intercellular space. The constriction at the top marks the limit of the lid. The part below the sporangium is the neck, with nutritive tissues.—Original.

Fig. 233.—A leaflet of a fern (*Aspidium*) seen from the back. Eight sori are shown, each covered by its own indusium, *i*. Magnified 2 diam.—After Sachs.

325. Horsetails.—In the horsetails the sporangia have the form of sacs, varying in number from six to twelve. They arise upon the lower face of a shield-shaped sporophyll (figs. 235, 236). These sporophylls are aggregated in a close cluster at the upper end of the axis, constituting what

may be called, properly enough, a flower.* The wall of the sporangium when young is formed by three layers of cells, but consists at maturity of one layer only, which, having its cell-walls thickened in an irregular manner (fig. 238), tears open the sporangium, usually along a vertical line. The wall of the spore consists of three layers, the outer one splitting into narrow strips and remaining lightly attached to the spore at one point (fig. 239). To these parts of the cell-wall the name elaters has also been given. (Compare ¶ 321.) Their

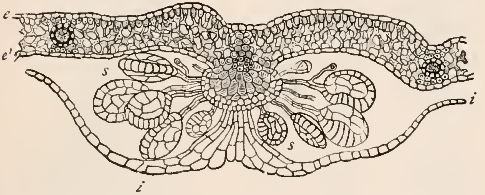


FIG. 234.—Vertical section through the leaflet shown in fig. 233, passing through the center of a sorus. *e*, ventral epidermis; *e'*, dorsal epidermis; between them the mesophyll, showing 3 veins cut across; over the central one is a cushion of tissue from whose surface arise the stalked sporangia *s*, *s*. *i*, *i*, the indusium. Magnified about 30 diam.—After Sachs.

purpose seems to be to entangle the spores so that they may not be too sparingly distributed.

326. Club-mosses.—In club-mosses the sporangia are saclike outgrowths upon the upper surface of the leaf near its base, or occasionally of the axis itself just above the leaf. Sometimes the leaves bearing them are the ordinary foliage leaves; in other species they are specialized and crowded into a terminal cluster or spike (fig. 240).

327. Differentiation of spores.—Among the higher fernworts the spores are of two sizes: large ones, known as mega-

* This term is not generally applied to these sporophylls. But see definition of a flower, ¶ 329, and compare fig. 237 of a "flower" of *Zamia*.

spores, and much smaller ones, known as microspores (fig. 241). Each kind, when it germinates, produces a sexual plant, or gametophyte (¶ 377), upon which, however, only

B *A*

Fig. 235.

Fig. 236.

Fig. 235.—Part of two sporophytes of a horsetail (*Equisetum arvense*). *A*, the spring shoots, with sheath-like whorls of leaves below and crowded sporophylls above *B*, summer shoots, much branched, with inconspicuous leaves; nutritive work all done by stems of these shoots. Two thirds natural size.—After Kerner.

Fig. 236.—Three sporophylls from the flower of a horsetail (*Equisetum telmateia*), seen in different positions. *s*, the shield-shaped sporophyll; *st*, its stalk attached to the center of dorsal face; *sg*, sporangia. Magnified about 10 diam.—After Sachs.

one sort of sexual organs is borne. The megaspores give rise to plants bearing female organs only, the microspores to

those bearing male organs only. A similar separation of sexes in the gametophytes frequently occurs when the spores are equal in size, as in Marchantia and horsetails, but it

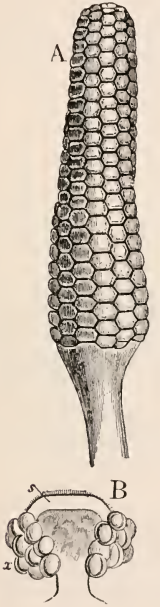


FIG. 237.

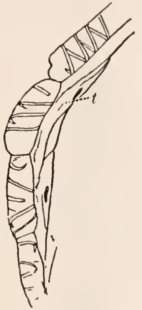


FIG. 238.

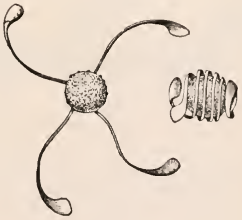


FIG. 239.

FIG. 237.—*A*, the "flower" of a seed plant (*Zamia muricata*). It is composed of crowded sporophylls, of which one is represented in *B* as seen from the side. It has a stalk capped by a hexagonal top, *s*, with numerous sporangia, *x*, on the under side. *A*, natural size. *B*, magnified about 6 diam.—After Karsten.

FIG. 238.—A bit of a section of the wall of a sporangium of a horsetail. The cells of the outer layer thicken their walls along spiral lines. The two inner layers of cells, *t*, become disorganized at maturity of the sporangium. Magnified 250 diam.—After Campbell.

FIG. 239.—Two spores of a horsetail (*Equisetum arvense*); one showing the elaters open, as when dry, the other with them coiled, as when moist. Magnified 25 diam.—After Kerner.

always occurs when they are unequal. A corresponding difference in size is often found between the sporangia containing small spores (*microsporangia*) and those containing large spores (*megasporangia*) (figs. 241, 242).

The sex terms, male and female, applicable primarily to the sex cells, are applied also to the organs and to the plants

FIG. 240.

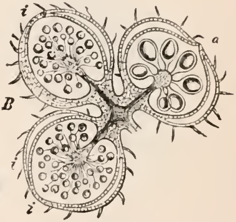


FIG. 241.

FIG. 240.—Sporophyte of a club-moss (*Lycopodium clavatum*). The horizontal stem is densely covered with leaves; those on the erect branch become small and few for a space; these are succeeded by broader leaves, the sporophylls, crowded in a dense spike, *s*. Half natural size.—After Prantl.

FIG. 241.—Section through three sori of an aquatic fernwort (*Salvinia natans*). Each is covered by a double indusium. *i*, *i*, two sori consisting of sporangia containing microspores (see fig. 242); *a*, a sorus consisting of sporangia, each containing one megaspore. Magnified 10 diam.—After Sachs.

which bear them, so that the microspores are said to produce male plants, and the megaspores female plants. For a further account of the gametophyte, see ¶ 386, 394, 393.

328. Seed plants.—In the seed plants this differentiation of the spores is always found. The microspores are called

pollen, and the megaspores are called *embryo-sacs*.* The microsporangia and megasporangia, also, are always different in form and structure, and the leaves upon which they are usually borne are also of two distinct forms. In no case do sporophylls perform nutritive work; they are always specialized. Those leaves which bear microsporangia are called *stamens*, and the leaves which produce the megasporangia are called

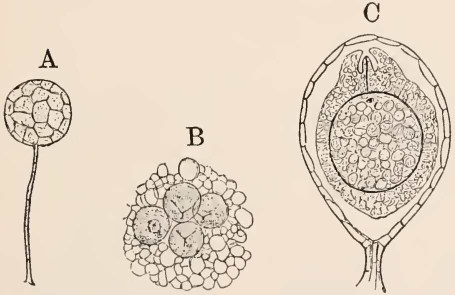


FIG. 242.—*A*, a microsporangium of *Salvinia* seen from the outside. It contains 64 microspores. *B*, four spores from *A*, surrounded by hardened frothy mucilage. *C*, median longitudinal section of a megasporangium, showing structure of wall at maturity, and the single spherical megaspore, with its proper wall (black line) and a thick frothy epispore (¶ 308). *A* and *C* magnified 55 diam. *B*, magnified 250 diam.—After Strasburger.

*carpels** (figs. 245, 250, 251). In spite of these special names, it must be carefully borne in mind that the sporangia and sporophylls of the seed plants are not different from those of the fernworts or mossworts in any essential particular.

329. The sporophylls of the seed plants are usually aggregated by the failure of the internodes of the axis to lengthen as much as between the foliage leaves. Very often, also, the

* These special names were given because the seed plants were first studied, and it was long before the real nature of the parts and their relation to similar ones in the lower plants were known. The terms are still in use, and are likely to continue to be used for convenience.

leaves adjacent are modified in form and color to adapt them to securing the dispersal of the pollen by various agents, especially insects. Such a shoot bearing sporophylls and accessory leaves is called a *flower* (¶ 330). As a similar aggregation of the sporophylls occurs in horsetails and many club-mosses (figs. 235, 240), it is evident that the flower is not distinctive of the seed plants, though it attains the highest specialization among them.*

The parts and functions of the flower of seed plants are now to be discussed.

The Flower.

330. A flower, in its simplest form, may consist of an axis bearing only a single sporophyll (fig. 243). A flower usually consists of a shortened axis, the *torus*, bearing several sporophylls and several accessory floral leaves (figs. 104, 244).

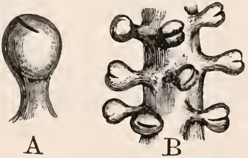


FIG. 243.

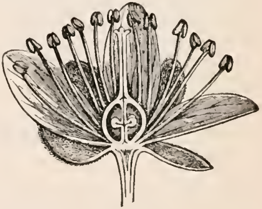


FIG. 244.

FIG. 243.—*A*, a single flower; *B*, a portion of the flower cluster of *Arisarum vulgare*. The flower is composed of one stamen only. Magnified slightly.—After Engler.
FIG. 244.—A flower of linden, halved; showing a pestle-like pistil. Magnified about 3 diam.—After Kerner.

The sporophylls are known as *essential organs*, the accessory leaves as the *perianth* and *bracts*.

The essential organs are of two sorts, *stamens* and *carpels*. In any flower they may be all stamens or all carpels, or may

* It is for this reason that the term *seed* plants is preferred to *flowering* plants.

include both sorts of sporophylls. The *perianth* may be composed of one or two kinds of leaves, often bright-colored. If there are two sorts, those next the sporophylls are generally highly colored, and constitute the *corolla*. Each leaf of the corolla, when distinct, is a *petal*. The leaves below the corolla are often green. They constitute the *calyx*, and each, when distinct, is a *sepal*.

331. Carpels. — The leaves (sporophylls) bearing the ovules (megasporangia) are called carpels. They may be flattened; or so curved that in the course of their development the edges unite and a cavity is more or less perfectly enclosed; or neighboring carpels may grow together in such a way as to form a case. Such hollow structures, whether composed of one or more carpels, are often somewhat pestle-shaped, whence they early received the name *pistil* (fig. 244). A flower whose only essential organs are pistils is called *pistillate*. The sporangia arise usually upon the ventral (inner) face or the edges of the carpels. In the open carpel they are exposed, but in the closed carpels they are completely shut in, except for a narrow opening which sometimes remains, by which the interior cavity communicates with the outside air.

332. Ovules.—Among seed plants the sporangia which the carpels bear are universally known as *ovules*, a name given to them under the supposition that they were the eggs which, upon fertilization, produce new plants. Though they are not in any respect comparable to the real eggs (since they are produced by the non-sexual or sporophyte phase), the name is retained for convenience.

333. Gymnosperms and angiosperms.—When the changes through which the ovule passes are complete, it becomes the *seed*. When the ovules are produced upon the free surface of an open carpel, the seeds are, therefore, exposed. On the contrary, when the ovules are borne within a closed pistil (formed by one or more carpels) the seeds are developed

within this case, by which they are protected until mature, or longer.

These two methods of seed production form the basis for the separation of the seed-bearing plants into two great groups, one known as gymnosperms, or plants with naked seeds, the other as the angiosperms, or plants with encased seeds. Open carpels are found exclusively among the gymnosperms, to which belong the cone-bearing, mostly evergreen, trees, while the closed pistils are chiefly found among angiosperms, to which belong the majority of garden and field plants and the deciduous forest trees.

334. The simplest form of carpel occurs in Cycas (fig. 245), in which the ovules are borne on the edges near the bases of leaves which somewhat resemble the foliage leaves, and form a whorl between preceding and succeeding whorls of foliage leaves upon the main axis. The carpel of most gymnosperms is a scale from whose upper surface arises a similar fleshy scale, the placenta, bearing two ovules upon its ventral (upper or in-

Fig. 245.

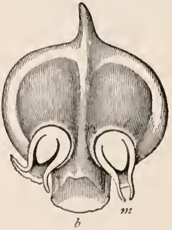


Fig. 246.

Fig. 245.—An ovule-bearing leaf or carpel of *Cycas revoluta*, showing 4 ovules near base, replacing the branches. On the right above, a young seed. About one quarter natural size.—After Sachs.

Fig. 246.—A young cone-scale (placenta) of Scotch pine showing the two ovules; the latter halved parallel to the scale, showing the body of ovule and the prolonged integument forming the micropyle, *m*. The scale is attached at *b*. Magnified about 8 diam.—After Kerner.

ner) face (fig. 246). In such cases the carpels are generally aggregated in close spirals near the end of a thickish axis, and finally ripen into a cone (figs. 341, 358), which gives the name to one of the largest orders of gymnosperms, the

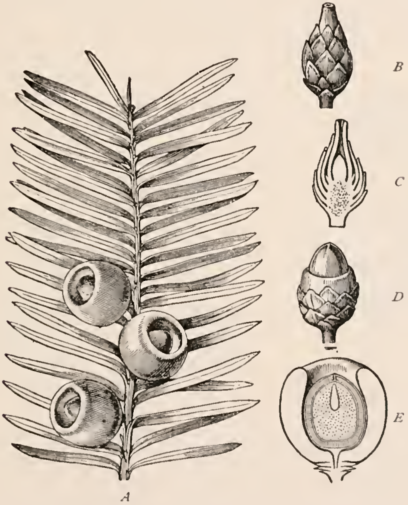


FIG. 247.—*A*, shoot of the yew (*Taxus baccata*) with three ripe seeds, each surrounded by a fleshy aril. Natural size. *B*, ovule with its tip projecting from the scale leaves of the shoot it terminates. *C*, the same, halved, showing the body of ovule (sporangium) and the long tube-like integument. *D*, young seed of same, with aril partly formed. *E*, mature seed, halved. The central (white) body is the embryo; around it (dotted) the food; then the seed coat; then the aril (white). *B*, *C*, *D*, *E*, slightly magnified.—After Kerner.

Coniferæ. (See further ¶ 404.) The ovules of some gymnosperms are not borne by carpels, but each terminates an axis, as in the yew (fig. 247).

335. The closed pistils of angiosperms are usually distin-

guishable into (1) an enlarged basal part, the *ovulary*,* containing the ovules, surmounted by (2) a slender part of variable length, the *style*, which is terminated by (3) a rough, sticky, or branched part, the *stigma*. (See figs. 250, 258.)

336. The stigma may take the form of a knob, a ridge, a straight or wavy line, or be lobed or branched. However compact, it is usually roughened by the prolongation of its surface cells into rounded, pointed, or hair-like extensions (figs. 248, 283), which frequently secrete a sticky fluid. Its purpose is to secure the adhesion of the pollen spores brought to it by various agents, among the most important of which are the wind and insects.

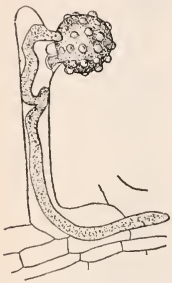


FIG. 248.—One of the hairs from the stigma of corn cockle (*Lychnis githago*) to which a pollen grain adheres. The pollen tube has penetrated the hair and is making its way down the style. Magnified 175 diam.—After Strasburger.

337. The style may be thick or slender, long or short, branched or unbranched, hollow or solid. It is frequently wanting, so that the stigma is said to be sessile upon the ovulary.

338. Simple and compound pistils.—When several carpels are present in one flower they may form as many separate *simple* pistils as there are carpels. If numerous, the axis will be enlarged or elongated to accommodate them. (See ¶ 360.) Instead of forming separate pistils,

* This part was early called the *ovary* (a name which is still in general use), meaning the organ which produces eggs, under the impression that the ovules (= little eggs) were like the eggs of birds, an idea which was further carried out in the name *albumen* given to the food stored in the seed. (See ¶¶ 403, 407.) To avoid confusion with the true ovary (¶ 388), in which the real egg is produced (¶ 387), I here suggest the name *ovulary*—i.e., the organ which produces ovules. The word ovule, though as bad in etymology as ovary, is convenient, and does not lead to any confusion.

the carpels may be united to form a single *compound* pistil. This union is commonly brought about (1) by the actual growing together of the parts in a very young stage, so that the cells interlock and become partially or completely united; or (2) the carpels develop, not as separate parts, but as a ring of tissue growing up from the surface of the axis; or, (3), a portion of each carpel develops separately, and later these distinct parts may be lifted by the growth of the ring of tissue beneath them (fig. 249).

339. The union * of the carpels may be only at the base; or it may involve the entire ovulary, leaving the styles free;

FIG. 249.

FIG. 250.

FIG. 251.

FIG. 249.—Pistil of white hellebore (*Veratrum album*) showing three carpels separate above only. Magnified about 6 diam.—After Berg and Schmidt.
FIG. 250.—Calyx and pistil of the manna ash (*Fraxinus ornus*) showing calyx leaves united at base and carpels united throughout, the slightly 2-lobed stigma only giving external evidence of their number. Magnified several diam.—After Berg and Schmidt.
FIG. 251.—Pistil of white potato halved transversely, showing two carpels united at center where their edges form a large placenta on whose surface the ovules arise. Magnified several diam.—After Kerner.

or the union may be complete, with the exception of the stigmas, or it may involve even them (fig. 250). Union may take place in such a way that the edge of each carpel meets its fellow and the edges of neighboring carpels in the center of the compound pistil (fig. 251). In this case the ovulary

* This phrase may be used for convenience in all cases, even of those pistils in which the carpels were at no time separate.

is divided into as many chambers as there are component carpels, and the partition by which the chambers are separated represents the adjacent parts of the two carpels. Or the carpels may unite with each other at their edges only, so that the line of union is at the outside of the pistil. In this case the ovulary will have a single chamber. In both these methods of union the normal number of chambers in the ovulary may be increased by outgrowths from the carpels themselves, as in figure 252, where from the united edges of the carpels a plate of tissue has grown out to meet a corresponding one from the other side, so that what should be a one-chambered pistil has become two-chambered. (Compare also fig. 276.) Even simple pistils are subject to such subdivision of their interior (fig. 253).

FIG. 252.—A transverse section of the capsule of shepherd's purse. The pistil consists of two carpels, at whose united edges two placentæ are formed carrying the ovules (now seeds). The partition from one placenta to the other is an outgrowth (false partition) and not part of the carpel. Magnified about 6 diam.—After Bessey.

FIG. 253.

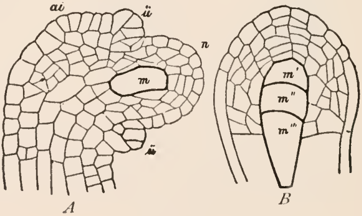


FIG. 254.

FIG. 253.—Lower half of the pistil of *Astragalus canadensis*. It consists of only one carpel, but is divided into two chambers by a false partition, an outgrowth from the midrib of the leaf. Magnified several diam.—After Gray.

FIG. 254.—Two stages in the development of the ovule of the currant. *A*, a median longitudinal section of a young ovule; *n*, the sporangium; *ii*, inner integument beginning to develop as a ring at base of *n*; *ai*, the fundament of the outer integument; *m*, the mother cell of the megaspores; *B*, a similar section of the sporangium alone, older, showing *m'*, *m''*, *m'''*, the daughter cells of *m*; *m'''*, only becomes a perfect spore; *m'* and *m''* do not develop further and become destroyed. Contents of cells not shown. Magnified 350 diam.—After Warming.

340. Ovules.—An ovule consists of a megasporangium partially enveloped by one or two outgrowths from beneath.

The sporangium forms the body of the ovule (fig. 254). In the interior the mother cells of the megaspores are differentiated early, the outer tissues forming the wall of the sporangium (fig. 254). In a few ovules as many as 20 to 40 megaspores begin to develop; in most only one to four. Even when several megaspores begin to form it is rare for more than one to reach perfection; the remainder disappear almost completely.

341. Indehiscence.—The megaspore never escapes from the sporangium; a condition which necessitates many adaptations. (See further ¶¶ 358, 414). The protection of the megaspore by the sporangium renders a thick wall unnecessary. For this reason the megaspore looks more like a cavity in the ovule than like a spore. Because an embryo appears later inside this apparent cavity, the megaspore of seed plants has long been called the *embryo-sac*.

342. Integuments.—The sporangium is surrounded by one or two integuments. These arise as outgrowths from the tissues adjacent. If the sporangium is to have two coats, the inner appears first as a low ring around its base gradually growing up around it; the outer shortly appears in the same way (fig. 255). These integuments, as well as the sporangium, often grow unsymmetrically, so that at the maturity of the megaspore the ovule is often variously curved (figs. 254, 255, 256). The megaspore itself may be distorted by this means so as to lose still more its likeness to a spore.

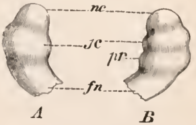


FIG. 255.—Two very young ovules of the California poppy (*Eschscholtzia*), seen from the outside. *B*, somewhat older than *A*. *nc*, the sporangium; *jc*, the inner integument; *pr*, the outer integument; *fn*, the stalk. Magnified 140 diam.—After Duchartre.

343. Location.—Ovules are borne either upon the axis itself or upon the carpels. When they are borne upon the axis they may be either uncovered, as in the yew

among gymnosperms (fig. 247), or the carpels* may form a covering, as in angiosperms. In these plants the ovule may terminate the axis, as in sunflower and buckwheat families (fig. 257); or the ovules may be lateral upon the surface of an enlargement of the axis within the ovulary, as in pinks and primroses (fig. 258).

It is usual, however, for the ovules to arise upon a carpel, either singly or in clusters which occupy definite portions of its surface. The cushion or ridge from which the ovules arise is called the *placenta*. In the pines the placenta is a

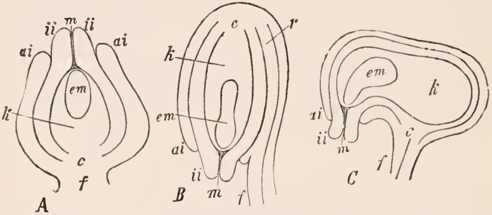


FIG. 256.—Diagrams of median longitudinal sections of three sorts of ovules to show curvatures due to unsymmetric growth. *A*, a straight, *B*, an inverted, *C*, a bent ovule. In all: *f*, the stalk; *k*, the sporangium; *ii*, the inner integument; *ai*, the outer integument; *m*, the micropyle; *c*, the base of the sporangium where the integuments arise (called the chalaza); *r*, the ridge (rhaphe) formed by the union of stalk and outer integument; *em*, the megaspore. As *C* develops further *em* may become sharply bent on itself.—After Prantl.

scale-like outgrowth from the upper surface of the carpel, bearing two ovules (fig. 246), and as the cones mature these gradually outgrow the carpels and constitute the main portion of the ripened cone. To such placentas the ovules are attached by one side; they are therefore entirely sessile. The

*Although the enclosing leaves in this case do not bear the sporangia, and are, therefore, not strictly sporophylls, their similarity in form renders it convenient to retain the name carpel even for those pistils in which they are a mere roof over a convex or hollowed axis bearing the ovules. (See fig. 258.)

placenta in angiosperms commonly consists of a cushion of tissue usually at the united edges of the carpel or carpels. If the carpels are united into a compound pistil, the placentas will be either isolated, as ridges upon the inner face of the wall of the ovulary (fig. 252), or aggregated at its center (fig. 251). Occasionally the ovules arise upon the entire inner face of the carpels, as in the gentians.

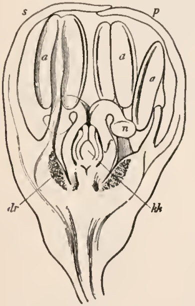


FIG. 257.

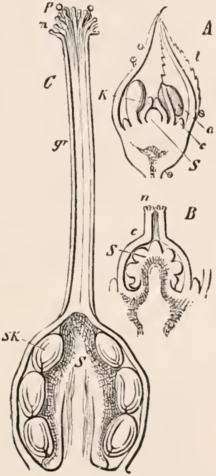


FIG. 258.

FIG. 257.—A median longitudinal section through the flower of *Rheum undulatum*. *s*, a sepal; *p*, a petal; *a*, *a*, *a*, anthers; *n*, stigma; *f*, ovulary; *kk*, sporangium, which, with the two integuments over it, forms the single ovule terminating the axis; *dr*, nectary. Magnified about 10 diam.—After Sachs.

FIG. 258.—Pimpernel (*Anagallis arvensis*). *A*, median longitudinal section of a young flower-bud; *l*, sepal; *c*, corolla, just beginning to develop; *a*, anther; *K*, carpels growing over *S*, the apex of the axis. *B*, median longitudinal section of the pistil. *c*, the carpels, forming a roof over *S*, the axis on which ovules are beginning to develop, and growing up to form a columnar style at whose apex is the stigma, *n*. *C*, the same, older. *S*, the enlarged apex of the axis showing six ovules, *SK*, in section; *gr*, the style; *n*, the stigma, on which are lodged pollen grains, *p*. All magnified.—After Sachs.

344. Stamens.—A stamen is a leaf (sporophyll) of the seed plants which bears the microsporangia, or pollen sacs. The flowers whose essential organs are all stamens are said to

be *staminate.* Rarely a single stamen constitutes a flower. Except for the crowding, the stamens are arranged like all the other leaves of the plant, arising on the axis alternately, or in one or more circles. The stamens exhibit great diversity of form and size. Each usually consists of two parts, a stalk, called the *filament,* bearing an enlarged portion, called the *anther.*

345. The filament may be long or short, slender or thick, rounded or flattened. It may be entirely wanting, in which case the anther is *sessile.*

346. The anther is usually larger than the filament and commonly two-lobed, having the sporangia located in the thicker parts. The sterile tissue between the sporangia is called the *connective* (fig. 262). This appears usually as a mere continuation of the filament, but sometimes is prolonged beyond the body of the anther, as an appendage (fig. 259).

FIG. 259.

FIG. 260.

FIG. 261.

FIG. 259.—Anther of the sweet violet (*Viola odorata*), showing the connective prolonged into a triangular tip. Magnified about 5 diam.—After Kerner.
FIG. 260.—Anther of thyme (*Thymus serpyllum*), showing broad connective. Magnified about 5 diam.—After Kerner.
FIG. 261.—Anther of the sage (*Salvia officinalis*). Opposite *a* the filament proper is jointed to the elongated connective which has one perfect anther-lobe on the upper end; on the other the sporangia do not develop. Magnified about 5 diam.—After Kerner.

It is sometimes broad, so that the sporangial lobes are widely separated (fig. 260), and may even be so long and slender as to seem a part of the filament (fig. 261).

347. Sporangia.—The anther bears from 1–12 microsporangia upon its surface, or wholly or partly sunk in its

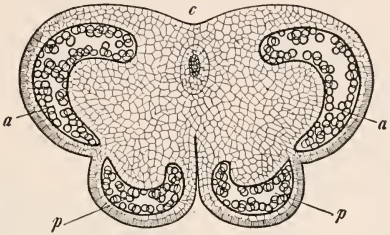


FIG. 262.—Transverse section of the anther of thorn-apple (*Datura Stramonium*). *c*, connective, with a small stele embedded in parenchyma; *a*, *p*, *a*, *p*, the four sporangia, arranged in pairs showing pollen grains. When the sporangia break, the walls rupture at the groove between *a* and *p*. Magnified about 25 diam.—After Frank.

tissues. In most anthers the sporangia are either 2 or 4 (fig. 262). When there are four they are often paired, and each pair may become confluent by the absorption of the portion of the anther tissue between them (fig. 263). This occurs about the same time that the outer wall bursts in order to set free the spores. Such anthers, at the time of opening, are apparently two-chambered. In those which contain only two sporangia, the two may open independently, or they may become confluent, so that at maturity they may seem to constitute a single chamber.

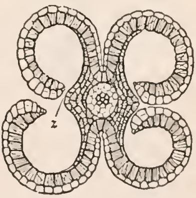


FIG. 263. Transverse section of bursted anther of a lily (*Butomus umbellatus*). Sporangia have ruptured at *z*, so that the two pairs have each formed a single cavity. The connective is relatively small; in the center a single stele. Magnified about 20 diam. After Sachs.

348. Dehiscence.—The opening of the chambers occurs in one of three ways: by pores, by slits, or by valves. (1) A small area of the outer wall is absorbed or breaks away so that the

pollen spores sift out through the pore so formed (fig. 264); or (2) a crack begins at one point and extends lengthwise of the sporangium, in which case the anther is said to open by slits (figs. 259, 260, 261); or (3) the break occurs along a line considerably curved, and the flap (valve) thus loosened curls up or lifts so as to allow the escape of the spores (fig. 265). All three methods are dependent upon some special

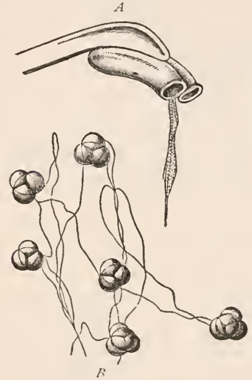


FIG. 264.

FIG. 265.

FIG. 264.—Anther and pollen of a *Rhododendron*. *A*, the anther, opening by pores at the end and allowing the pollen to escape. Magnified 8 diam. *B*, pollen grains adherent in fours (tetrads) as formed in the mother cells; the tetrads are held together by a sticky material which draws out into cobwebby threads as they are separated. Magnified 50 diam.—After Kerner.

FIG. 265.—A flower of cinnamon, halved. The calyx and stamens are raised on a cup developed around the pistil. The anthers open by uplifted valves, one for each sporangium, which here are arranged in two stories instead of in pairs side by side. Magnified about 7 diam.—After Luerssen.

structure of the wall of the sporangium at the lines of rupture.

349. Union.—The stamens are not infrequently united with each other or with some of the neighboring leaves of the flower. They may be united to each other by their fila-

ments only, or by their anthers only, or throughout their whole length. Union with the pistil or pistils is rather uncommon, but union with the corolla or calyx is very frequent.

The union of stamens may be real or apparent. They may develop independently and later cohere by their adjacent edges (fig. 266). Or they may begin development separately and be subsequently raised by the growth of a ring of tissue of the torus (¶ 360), so that the free portions arise from the top of a shorter or longer tube. When the stamens and corolla, arising independently, are carried up together by the growth of such a zone of the axis, the stamens appear to arise from the surface of the corolla (fig. 267).

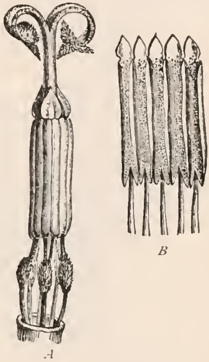
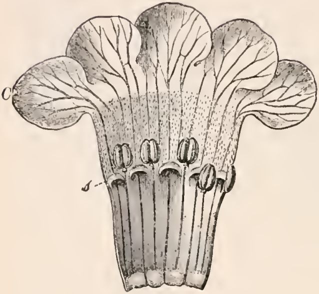


FIG. 266.—The stamens of one of the sunflower family (*Cosmos bipinnatus*). *A*, stamen tube formed by five stamens coherent by their anthers around the style; the filaments with a tuft of hairs about the middle. *B*, the same, but stamens only; the tube has been slit along one side and opened out flat; seen from the inside. Connective prolonged; dehiscence by slits. Magnified about 7 diam.—After Baillon.

350. Branching. — The stamens frequently branch, and this is difficult to distinguish from the displacement by basal growth just described, except by studying their development. When stamens branch a single fundament appears, on which later arise smaller knob-like elevations, the fundaments of the branches, each with its own growing point. (See figs. 268, 269, 270; also ¶ 171 and figs. 146, 166 on branching of leaves, of which this is only a special case.)

351. Pollen grains.—The microspores produced in the sporangia of the stamen are at maturity single cells. Their forms and walls are various, being round, ovoid, or even angular, with the surface smooth, grooved, or roughened with

few or many bosses, points, or ridges, as in other spores (A–D, fig. 271). In the pines the outer layer of the wall



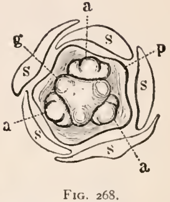


FIG. 268.

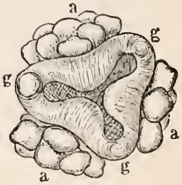


FIG 267. FIG. 269.

FIG. 267.—Corolla of *Alcanna tinctoria* slit and laid open, showing almost sessile stamens united with corolla above the middle of tube. *s*, scale-like outgrowth from corolla. The tube between *s* and the notches at edge of corolla result from the growth of a ring of tissue beneath the five fundaments of the corolla which produce the five corolla lobes *c*. Having grown so far, a ring of tissue inside, on which the stamen fundaments were developing, became involved in this upward growth, and thus the stamens were carried up and arise just above *s*. Magnified 4 diam.—After Berg and Schmidt.

FIG. 268. Very young flower of *Hypericum perforatum*, seen from above, showing *s*, sepals; *p*, fundaments of petals; *a*,*a*,*a*, fundaments of the three stamens, each already with two lateral growing points, the fundaments of branches, appearing; *g*, fundaments of 3 carpels. Compare with figs. 269 and 270. Magnified about 50 diam.—After Frank.

FIG. 269.—An older stage of fig. 268, showing only the fundaments of stamens, *a*, and of carpels, *g*. On the latter at the angles appear the fundaments of the three styles. Many branches of *a* have begun. Compare fig. 270. Magnified about 50 diam. —After Frank.

forms two bladdery swellings which make the spore relatively lighter (E, fig. 271). The pollen spores arise in the sporangia in fours in each mother cell, as described in ¶ 306. (See also fig. 264.) They are either dry and powdery when

the sporangia burst, or are moist and sticky, adhering to each other in larger or smaller clusters (fig. 264). Sometimes, as in orchids and milkweeds, they are all held together in one mass by the remnants of the mother cells in which they were formed, and are attached to a part of the tissue of the anther which carries the mass as a stalk or handle (figs. 272, 273). Dry spores are usually adapted to distribution by wind; while the adherent spores are adapted to carriage by small animals, especially insects. (See further ¶ 481.)

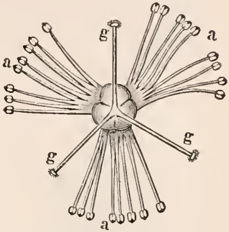


FIG. 270. – Mature condition of the stamens and carpels of fig. 269. *a*, 3 branched stamens; *g*, three carpels with bases united and only the styles distinct. Compare with figs. 268, 269. Magnified about 3 diam. – After Frank.

352. Germination in place.—By the time the sporangia

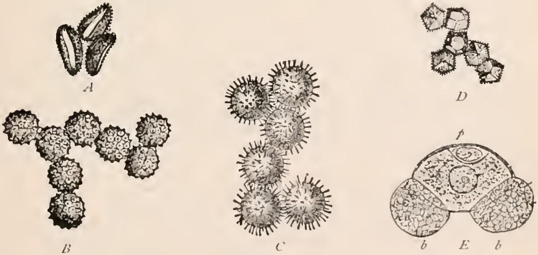


FIG. 271.—Pollen grains. *A*, white water lily (*Nymphæa alba*). *B*, a thistle (*Cirsium nemorale*). *C*, a mallow (*Hibiscus ternatus*). *D*, dandelion (*Taraxacum officinale*). Magnified 200 diam.—After Kerner. *E*, pine, showing bladdery enlargements, *b*, *b*, of the outer layer of the cell-wall. The central portion is the body of the spore filled with protoplasm with a large nucleus. From it is separated a lenticular cell, *p*, the rudiment of the gametophyte. Magnified 400 diam.—After Strasburger.

are old enough to release the spores, the latter have already germinated and begun to form a new sexual plant, the male gametophyte. Thus the spores of the non-sexual plant give

rise to a plant of the other or sexual phase; the sporophyte produces the gametophyte. (For a description of the plant thus formed see ¶ 385.)

353. Perianth.—The perianth is not present in any

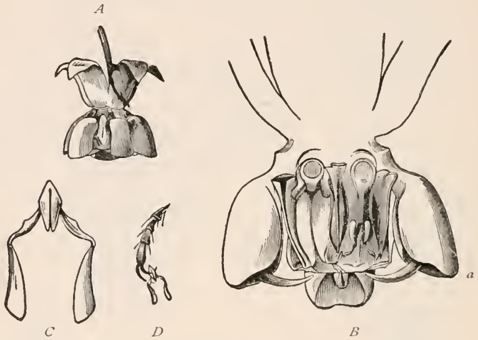


FIG. 272.—*A*, hanging flower of milkweed, seen from the side. The petals are sharply reflexed. Natural size. *B*, the upper part of same, magnified about 2½ diam., with two of the appendages, *a*, of the stamens cut off and the front of the anther wall dissected away to show its two pollen masses. *C*, two pollen masses from neighboring anthers connected to a clip, by which they may be attached to the foot of an insect. Magnified about 8 diam. *D*, foot of an insect with pollen masses attached. In *C* and *D* the pollen masses are inverted as compared with their position in *A* and *B*.—After Kerner.

gymnosperms (¶ 333), except in a rudimentary form in a few species of the highest order. In angiosperms the perianth, which is rarely wanting, is primarily for the protection of the sporophylls. As in all cases where leaves are produced rapidly and in close proximity on a short axis, they grow during their early stages more rapidly upon the outer face than the inner. They are, therefore, concave inward and closely pressed together, forming a bud. At a certain stage the growth upon the two faces of the

perianth becomes equal, and later is more rapid upon the inner face than the outer. At this time the flower unfolds, the perianth spreading more or less and exposing the stamens and pistils within. These variations in growth are often repeated, the stimulus being light or heat or both, when it is necessary to protect the spores against unfavorable weather. Such flowers open and close several times before their leaves wither. (See also ¶ 286.)

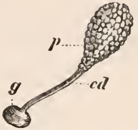


FIG. 273 — Pollen mass from an orchid. The pollen grains are arranged in packets, *p*, which are aggregated at the end of a stalk, *cd*, terminating in an enlarged sticky disk, *g*, by means of which the pollen mass adheres to insects. Magnified about 10 diam.—After Engler.

354. Calyx and corolla.—The leaves of the perianth are usually arranged upon the torus in two or more circles or in a low spiral. They may be all alike or differentiated into two series, an outer and an inner. In the latter case those of the outer row or rows constitute the calyx, and the inner set the corolla.

355. The calyx.—The calyx leaves, or *sepals*, are generally green and possess a great variety of form. When separate, the sepals are usually sessile and broad, with more or less pointed apex. The sepals are often apparently united in the manner already described for the stamens, the originally separate portions appearing as teeth or lobes at the rim of a cup or tube, or some similar structure. Occasionally the sepals are not persistent, but fall as the bud opens or shortly thereafter. More commonly, however, the calyx, especially when undivided, remains throughout the entire development of the flower, and often of the fruit.

356. The corolla.—The inner set of perianth leaves, the petals, constitutes the corolla. The corolla presents a greater variety of form and color than does the calyx. The petals may be sessile or have a short or long stalk (fig. 274). The corolla may develop a cup or tube, as described for the calyx, with teeth or lobes representing the petals (*c*, *c*, fig. 267). It

may be lifted on a common tube with the calyx from which it then seems to arise; or it may be raised with the stamens, which then seem to be attached to it, as in figure 267; or stamens, corolla, and calyx may be lifted together (figs. 288, 355). The corolla is ordinarily not persistent, usually falling or withering shortly after the microspores have been lodged upon the stigma.

Fig. 274.—Outline of a petal of *Lychnis*, showing long stalk and an outgrowth, *n*, the ligule. Compare fig. 137.—After Luerssen.

357. Irregularity. — Both corolla and calyx are often radially symmetrical—i. e., the parts surrounding the center of the stem are of equal size and like shape, and may be divided into several like halves by radial planes (figs. 275, 276). But often the symmetry of the calyx, and still more frequently that of the corolla,

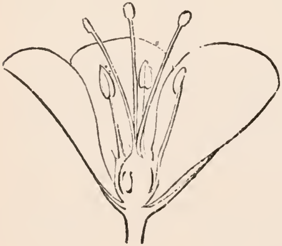


Fig. 275.

Fig 276.

Fig. 275.—A flower of the flax, halved; showing radial symmetry. See fig. 276. Magnified 2 diam.—After Bessey.

Fig. 276.—Diagram showing the arrangement of the parts of a flower of flax. Outer circle, 5 sepals; second, 5 petals; third, 5 stamens; fourth, 5 carpels, each divided by a false partition into 2 chambers. Five different radial planes will, therefore, divide this flower into halves.—After Bessey.

is so altered by unequal growth of the parts that the flower can be divided into like halves by only one, or at most two,

planes; or it may even be entirely unsymmetrical. This unlikeness in the size and shape of the accessory leaves not infrequently extends to the sporophylls (figs. 277, 278).

The irregular form and color of the perianth (when other than green), including the variegation of the ground color by lines and spots, seem to be dependent upon the relation of the flower to insects. (See further ¶ 484.)

FIG. 277.

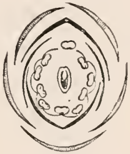


FIG. 278.

FIG. 277.—An unopened flower of the sweet pea, halved; showing bilateral symmetry (irregularity). Slightly enlarged.—After Bessey.

FIG. 278.—Diagram showing the arrangement of the parts of the flower of sweet pea. Outer circle, calyx (5-lobed); second, 5 petals, the two lower united; third, 10 stamens, 9 united by filaments, 1 separate; center, one carpel. Only one plane will divide this flower into halves.—After Bessey.

358. Pollination.—Since the megaspore is enclosed permanently by the ovule, and in angiosperms the ovules are again enclosed by the pistil, it is necessary that the male plant growing from the pollen spores be developed in the neighborhood of the ovule whose megaspore produces a female plant. (See ¶¶ 341, 386.) To insure this a portion of the pistil forms a receptive surface, the stigma, upon which the pollen spores may be readily lodged. It is advantageous, also, to have the pollen spores of one flower lodged upon the stigma in another flower of the same sort rather than upon the stigma of the same flower. The process of lodgment of pollen on a stigma is called pollination. If the pollen from one flower is carried to the pistil of another, it is called cross-pollination.* To secure pollination, and especially

* Since fertilization of the egg is the ultimate object of pollination and

cross-pollination, the agency of wind or water or insects is employed. To the peculiarities of these various agents, flowers adapt themselves in character of pollen, color, nectar, odor, form of parts, time of development of stamens and stigma, etc. For an account of these see ¶¶ 477–482.

359. Bracts.—In the immediate neighborhood of the perianth the leaves are usually modified at least in form and size, and not infrequently in color. The leaves in whose axils the flowers arise are called bracts, as are also those which subtend branches of the inflorescence (h^1, h^2, h^3, fig. 139). The axis of the flower, when elongated beneath it, usually bears one or more bractlets.

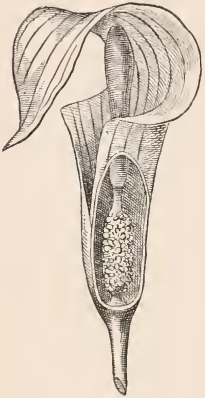


FIG. 279.—Inflorescence of Indian turnip (a *spadix*), surrounded by a large striped and mottled bract, the *spathe*. Natural size. —After Gray.

The bract is sometimes large and surrounds the entire inflorescence, as in Indian turnip (fig. 279) and the calla, when it may be variously colored. Highly colored bracts occur in the scarlet sage and, with inconspicuous flowers, in poinsettia and painted cup, while the four large whitish bracts of dogwood are the only conspicuous part of the inflorescence (fig. 280).

Bracts are aggregated to form an *involucre* beneath a head (¶ 104), as in the sunflower family (figs. 281, 409), or an umbel (¶ 104), as in the parsnip. The perianth may be almost or quite wanting, and the bracts and bractlets may be the only protective leaves for the sporophylls, as in the

generally its final result, the terms close- or self-fertilization and cross-fertilization were formerly used. The word pollination is preferable.

FIG. 280.—Inflorescence of the dogwood (*Cornus florida*), showing four white bracts below it, giving the whole cluster the aspect of a single flower. Two thirds natural size.—After Baillon.

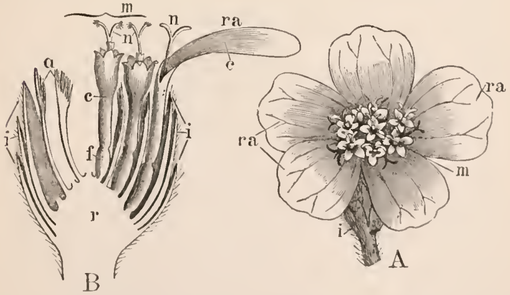


FIG. 281.—Inflorescence of yarrow (*Achillea millefolium*). *A*, seen from above; *B*, in longitudinal section. *i*, bracts, forming the involucre; *d*, bracts in whose axils the flowers stand; *ra*, the ray flowers; *m*, the disk flowers; *c*, corolla; *f*, ovulary; *n*, stigmas; *r*, the common torus. *A* magnified about 8 diam.; *B*, about 15 diam.—After Prantl.

grasses (fig. 282). Bractlets sometimes form a sort of second calyx beneath the true calyx, as in hollyhock. In the strawberry and its kin, the somewhat similar extra whorl of leaves

FIG. 282.

FIG. 283.

FIG. 284.

FIG. 282.—A single flower of wheat, showing two chaffy bracts, *b*, *v*, which protect it. For the parts of the flower see fig. 283. Magnified about 5 diam.—After Luerssen.

FIG. 283.—The flower of wheat with bracts removed, showing two fleshy bractlets, *c*, *c*, the lodicules, which at time of blossoming swell and open the bracts. Three stamens, and a carpel with two styles and feathery stigmas constitute the flower proper. Magnified about 5 diam.—After Luerssen.

FIG. 284.—Outline of the flower of strawberry, seen from beneath. *c*, corolla; *k*, calyx; *k'*, epicalyx, formed by the union of the stipules of the sepals. Slightly reduced.—After Luerssen.

belongs to the calyx, being the stipules of the calyx leaves united in the course of development (fig. 284).

The "cup" of the acorn, the "shuck" of the beechnut, and the "bur" of the chestnut represent late-developed outgrowths beneath the flower or the flower cluster, which become scaly or spiny as the nut develops, and serve to protect the forming fruits.

360. The torus.—In the vicinity of the flower leaves the internodes of the stem are rarely developed, so that the nodes from which the flower leaves arise are close together. Moreover, the axis is usually enlarged, so as to give greater space for the numerous leaves. This enlarged portion is called the *receptacle* or *torus*. When the leaves are removed or fall naturally the torus shows ordinarily a rounded or conical surface, with close-set scars left by their bases (fig. 285). When

a great number of sporophylls are to be borne, the torus is elongated, as in the mousetail (fig. 286); or greatly enlarged,

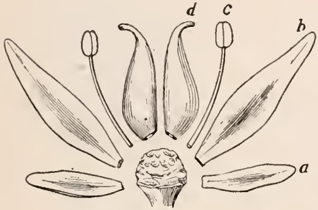


FIG. 285.

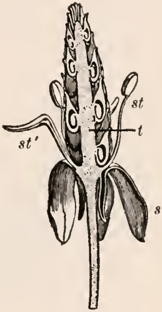


FIG. 286.

FIG. 285.—The torus of a flower of stonecrop (*Sedum ternatum*), with the leaves removed to show scars; two leaves of each kind shown. *a*, sepal; *b*, petal; *c*, stamen; *d*, carpel. Magnified several diam.—After Gray.

FIG. 286.—Flower of mousetail (*Myosurus minimus*), halved; showing *s*, spurred sepal; *st*, stamen; *st'*, a staminode or sterile stamen, having the position and form of a petal; *t*, elongated torus covered with carpels, some of which are cut through. Magnified several diam.—After Engler.

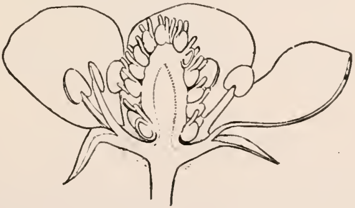


FIG. 287.—Flower of the strawberry, halved; showing elongated and thickened torus. Magnified about 3 diam.—After Bessey.

as in the strawberry (fig. 287); or transformed into a cup, as in the rose (fig. 288).

When flowers in large numbers are very closely associated,

as in a head (¶ 104), the receptacles are joined to form a large common receptacle, as in the sunflower and its allies (fig. 281). The receptacle in such plants may be a cone, a dome (fig. 409), or a more or less flattened disk. In the

Fig. 288.

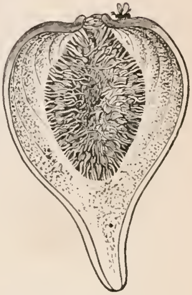


Fig. 289.

Fig. 288.—Flower of sweetbrier rose, halved; showing urn-shaped torus. Compare fig. 139. Natural size.—After Bessey.

Fig. 289.—The inflorescence of fig, halved lengthwise; showing common torus on whose interior surface many flowers are formed. Two fig wasps are near the opening of the flower chamber, one outside, while the other has just crawled in among the flowers. Natural size.—After Kerner.

fig the common receptacle is pear-shaped, with the edges almost meeting above and the flowers distributed over the inner face of the fleshy sac (fig. 289).

III. Brood buds, etc.

361. Definition.—Single-celled spores pass without any sharp distinction into the multicellular bodies known as brood buds. For convenience, however, brood buds may be defined as multicellular (sometimes unicellular) bodies capable of producing a new plant of the same phase as that from which they arise. Since this is a distinction for convenience merely, it is not desirable to distinguish brood buds

from spores until the mossworts are reached, in which the alternation of phase is well marked. In their simplest form such buds consist of a single cell, though more commonly they are two- to several-celled. Some or all of their cells are in the embryonic stage (¶ 256). Like spores, they are supplied with reserve food.

362. Simple forms.—The form of brood buds is various. When not differentiated into distinct organs, they are club-shaped, lenticular, or spherical. In some thalloid liverworts (*Marchantia* and *Lunularia*) they are produced on the surface of the thallus, surrounded wholly or on one side by an outgrowth from the surface forming a cup or a crescentic ledge (figs. 59, 290, 291). In some mosses brood buds arise from

FIG. 290.—Thallus of Marchantia, seen from above, showing the cups containing brood buds. See fig. 291. Natural size.—After Kerner.

the apex of the stem, either in cup-like clusters of leaves or exposed (*A*, *A′*, fig. 292); in others they are smaller and simpler and are developed upon the leaves (*B*, *B′*, fig. 292). In all the mossworts they belong to the gametophyte.

363. Shoots.—In fernworts and seed plants the brood buds belong to the sporophyte. In the latter they are especially abundant, and often reach considerable size and complexity before being separated from the parent, usually consisting of a short axis with a growing point and at least rudimentary

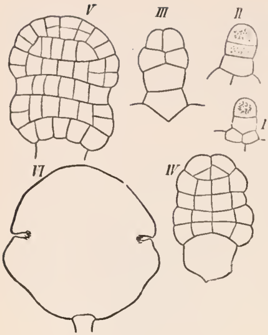


FIG. 291.

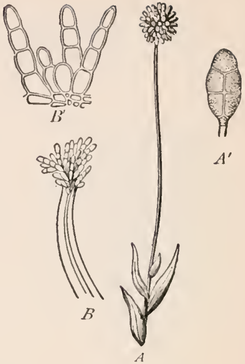


FIG. 292.

FIG. 291.—Six stages in the development of a brood bud of Marchantia; all seen from side. I, very young, the originally single cell projecting from bottom of cup (fig. 290) divided into a stalk cell and terminal cell. II, older, terminal cell divided transversely. III, IV, V, successively older stages. VI, mature, cells not shown; two growing points localized on right and left edges. I-V, magnified about 250 diam.; VI, about 25 diam.—After Sachs.

FIG. 292.—Brood buds of mosses. *A*, upper part of the stem of *Aulacomnium androgynum*, with a cluster of brood buds at apex (magnified about 8 diam.), one of which is enlarged 120 diam. in *A'*, *B*, tip of leaf of *Syrrhopodon scaber* (magnified about 10 diam.) showing brood buds; *B'*, some more enlarged (about 40 diam.).—After Kerner.

FIG. 293.—Young plants developing from adventitious buds on leaves of a fern (*Asplenium bulbiferum*), from which they readily separate to form new plants. *A*, natural size. *B*, magnified 2 diam.—After Kerner.

leaves. They generally arise upon the stem, more rarely from the leaves or the root. Upon the stem they usually take the place of shoots of other forms, developing from axillary buds (figs. 294, 296). If formed on leaf or root it is always from adventitious buds (fig. 293).

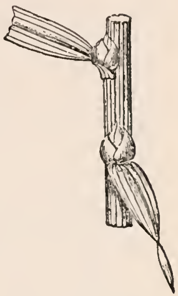


Fig. 294.—Fleshy buds in axils of the leaves of a lily (*Lilium bulbiferum*). Somewhat reduced. — After Van Tieghem.

Every possible gradation exists, from the simplest to those with well-developed members, constituting a plant of some size. They may be artificially grouped as follows:

364. (*a*) **Buds.**—In these the axis is short and the leaves scale-like. When most highly developed the quantity of reserve food is considerable and the

Fig. 295.—Pond weed (*Potamogeton crispus*). Detachment of special shoots, hibernacula, which are to hibernate under water. The plant *A* has one of these shoots at the tip; *B* has just loosened one, *h*, which is sinking to the bottom. Two thirds natural size.—After Kerner.

parts of the bud are often distorted by the enlargement of the tissues to contain the food. The fleshy buds which readily separate from the axils of the leaves of some garden lilies (fig. 294), and those which replace the flowers in some cultivated onions, are well known. (Compare also fig. 106.)

365. (*b*) **Hibernacula.**—Somewhat similar but more highly de-

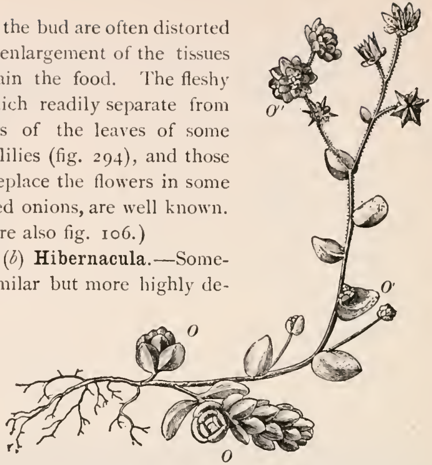


FIG. 296.—A plant of stonecrop (*Sedum dasyphyllum*). Offsets are produced near the base on short branches o, o; at the tip of longer branches, o'; and in place of the flowers, o''. Natural size.—After Kerner.

FIG. 297.—Formation of runners in the strawberry. a, the mother plant; b, young plant formed at tip of first runner; c, plantlet at tip of second; a third has put out from c. Slightly reduced.—After Seubert.

veloped brood buds are formed at the approach of winter about the base of the stem in many perennials with herbaceous tops. These are separated by the death of the parent stem and produce new plants in the spring. Some aquatics show a similar habit, dropping short shoots to the bottom of the water in autumn, which are to grow in the spring (fig. 295).

366. (*c*) **Offsets, etc.** — Some plants produce special branches, either underground or aerial, which develop at their extremities new plants or special structures for their formation. The house-leek or live-forever (fig. 369) and stonecrop (fig. 296) reproduce themselves by offsets. These are short branches with a rosette of leaves at the tip which is readily detached and rolls away, to take root at the first opportunity and establish a new plant. The strawberry and eel-grass form long leafless branches which take root at the tip and produce new plants, the slender runner subsequently perishing (figs. 297, 298). The white potato forms at the end of slender underground branches elongated tubers upon which are numerous buds, any one of which, nourished by the reserve food in the tuber, may produce a new shoot. The slender stem by which the tuber is connected with

FIG. 298.—A plant of eel-grass (*Vallisneria spiralis*) forming new plants, *a*, *b*, at tips of runners, arising from axils of lower leaves. One third natural size.—After Schnizlein.

the main axis perishes at the end of the growing season (fig. 299).

367. (*d*) **Cuttings or scions.**—Closely related to this mode of reproduction is that by the separation of fleshy

FIG. 299.—A seedling potato plant. *c* is the base of the stem, below which is the primary root, *r*. The primary leaves *ct*, are still present. The early leaves, *f*, are not so much branched as later ones will be. In the axils of the lower leaves arise the branches *b*, with scale leaves, *e'c*, and secondary roots, *r'*. The tips of these branches, when illuminated, bear foliage leaves, *f'*; but usually they thicken into tubers, *tb*, which have scale leaves, *e'c'*, in whose axils buds, *br*, are formed, the so-called "eyes" of the tuber. Natural size.—After Duchartre.

members, upon which are subsequently developed adventitious buds, which give rise to new plants. The thick leaves of *Bryophyllum* are often blown off by storms, and produce new plants from buds formed at the teeth along the edge.

Some species of *Kleinia*, natives of Cape Colony, have fleshy stems, jointed at intervals, so that they easily break there. When broken off by an accident, the piece rolls away, takes root from the under side, and sends up shoots from the upper.

Advantage is taken of this power of severed parts to form adventitious roots and shoots in the artificial propagation of domestic plants. Suitable portions of shoots or leaves for the development of new plants under proper conditions are called cuttings, scions, or "buds." They may generally be grown in water or soil; or they may be securely fastened in a slit or wound in another plant. The latter process is known as grafting or budding, according to the form of the implanted part. Indeed brood buds in general may be looked upon as natural cuttings or scions.

368. Branching.—A further modification of this method of reproduction is to be observed in the formation of new individuals through progressive death of the older parts. If a plant, dying thus, be a branching one, death will sever the branches as it reaches them sooner or later, and each branch then becomes an independent plant. This is seen in its simplest form in those plants which have a horizontal branching thallus whose base dies as the apex elongates (fig. 300). It is common in plants with underground creeping stems which send up aerial leaves or shoots annually, as do the ferns of temperate regions and many grasses and mints.

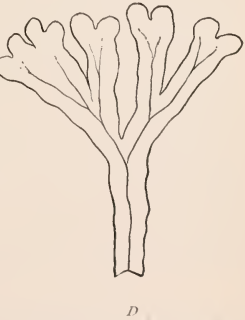


FIG. 300.—Outline of a thallus of *Marchantia geminata*. The base *D* is dying as the apices are growing and branching. When death reaches the first fork there will be two independent plants; at the second there will be four, and so on.

CHAPTER XVIII.

SEXUAL REPRODUCTION.

369. Cell union.—All methods of sexual reproduction consist in the formation of a single cell by the union of two specialized cells, known, respectively, as the male gamete and the female gamete. The essential step in their union is the coalescence of the nuclei. The cell thus formed is capable of developing into a new plant under suitable conditions, and is, consequently, a *spore*. Such sexually produced spores must not be confounded with non-sexual spores (see ¶ 304).

370. Origin.—It is scarcely to be doubted that the earliest methods of reproduction were vegetative, and that sexuality has been acquired by a gradual modification of cells previously devoted wholly to ordinary processes of growth. The probable history of the origin of sexual cells and sex organs can only be inferred from the fact that the simplest plants show no sexuality, others show imperfect sexuality, and still others complete sexuality. The data are very imperfect, but they enable us to form at least an intelligent idea of how sexuality *may* have been acquired.

Theory of sexuality.

371. Rejuvenescence.—Among the processes of growth in the simpler plants, especially the fission-algæ (¶ 11), one of the most striking is that known as rejuvenescence. In this process the protoplasm of the cell escapes from the cell-wall, and acquires special motor organs known as cilia, which en-

able it to swim rapidly, but apparently aimlessly, through the water. In this form it is essentially a zoospore. (See ¶ 306.) After having moved about for a variable time and perhaps increased its volume by growth, it loses its cilia, surrounds itself again with a cell-wall, and resumes its ordinary mode of life. In filaments of some multicellular algæ a similar process occurs. The contents of any cell may escape by the solution of the cell-wall and become a zoospore. After swimming about for a time the zoospore may come to rest, secrete a cell-wall, and by repeated divisions in one plane produce an individual similar to the parent. (See ¶ 24.) It is evident that such a method would give rise economically to a considerable number of individuals. The process is essentially the separation of the filament into pieces, each being the contents of a single cell.

372. Conjugation.—In other filamentous algæ the cell-contents, instead of escaping as a single zoospore, divide into two or more zoospores. If, while these are still active, two accidentally collide, the possibility of their adherence and and the fusion of the two into one is conceivable. Such fusion actually occurs among the zoospores of algæ, and is called conjugation. But in observed cases it follows a definite method, and is not merely accidental. It is probable, however, that the first occurrence of conjugation was accidental, and that it has become fixed and definite because those individuals in which it occurred with most certainty and regularity thereby produced the most vigorous offspring.

373. Imperfect sexuality.—In the alga *Ulothrix*, we have a plant in which many of the processes just described still occur. It produces zoospores of two kinds: (1) large ones, with four cilia (*C*, fig. 301), formed in pairs in each cell (*B*); (2) small ones, having two (rarely four) cilia, and arising eight or sixteen from each mother cell (*D*). Both these sorts of zoospores will grow, after a period of swimming, into new

plants, though the small ones produce very slender, weak filaments (fig. 302). Beside the zoospores, *Ulothrix* produces, under certain conditions, gametes, which are precisely like

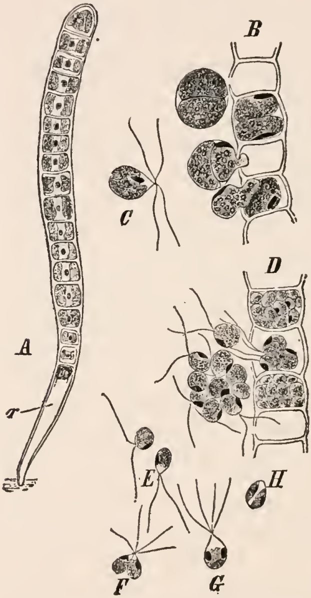


FIG. 301.—*Ulothrix zonata.* *A*, a young filament with rhizoid cell, *r*, at base. *B*, bit of a filament from whose cells large zoospores are escaping through a pore in the side-wall. *C*, a single large zoospore. *D*, bit of a filament from whose cells small zoospores (or gametes) are escaping. *E*, small zoospores (or gametes). *F*, gametes conjugating. *G*, same, conjugation complete. *H*, zygote, before formation of wall to become a resting spore. Magnified 482 diam.—After Dodel-Port.

the small zoospores in appearance. But their behavior is different. They usually conjugate freely in pairs and produce resting spores. If, however, they do not conjugate, each

may round itself off and, alone, become a resting spore. These resting spores, after a dormant period, germinate and develop into new plants.

In *Ulothrix*, therefore, the gametes are imperfectly sexual. Failing to conjugate, as many do, they may still develop into new individuals. A consideration of the appearance and behavior of the gametes leaves little doubt that they are merely small zoospores which have acquired imperfectly the habit of conjugation and retained partially the power of independent growth.

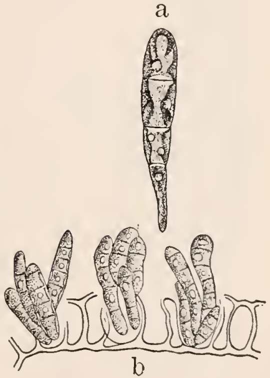


FIG. 302.—Sporelings of *Ulothrix zonata*. *a*, a young plant from a large zoospore. *b*, young plants from small zoospores which germinated without leaving the mother cell. Magnified 482 diam.—After Dodel-Port.

374. Further development.—The perfecting of reproductive methods followed the two lines just suggested. On the one hand, complete sexuality was acquired by certain cells, while others were more completely specialized as non-sexual reproductive bodies. The latter have already been discussed (¶ 304 ff.).

Tracing now only the line of sexual development, it is probable that the first step in this differentiation was the failure of some of the zoospores to escape from the cell producing them. From this point two lines of development diverge.

375. 1. **Isogamy.**—Along one of these lines, the zoospores ceased to form cilia, and became non-motile sex cells, in some cases similar in form and function, and in others

like in form but unlike in behavior. This leads to the completest form of conjugation, as seen in *Mesocarpus*, *Spirogyra*, and other Conjugatæ. (See ¶ 25.) In these the contents of one cell of a filament enter those of another either by a partial solution of the partition-wall between them or by the formation of a tube-like outgrowth from one or both of the cells concerned, so that when these tubes come in contact and have their ends absorbed the contents of one cell passes over into that of the other (fig. 303). The cells conjugating in this way may be either neighboring cells of the same filament or cells of different filaments brought into proximity by accident. In the course of development in this direction conjugation reaches its highest perfection, being secured with such certainty that non-sexual methods are almost entirely abandoned.

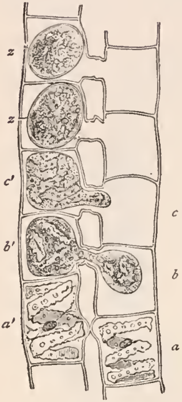


FIG. 303.—Conjugation of *Spirogyra quinina*. The cells *a*, *a'* are just forming the conjugating tube; the contents not yet fully reorganized as gametes. The body protoplasm is not shown in these two cells, though it is in the others (compare fig. 25, of another species of Spirogyra). The cells *b*, *b'* have completed the tube; the ends have been dissolved and the contents of *b* is passing over into *b'*. This process is nearly completed in cells *c*, *c'*. *z*, *z*, zygotes, with protecting wall, thereby prepared to become resting spores. Magnified 150 diam. — After Strasburger.

376. 2. **Heterogamy.**—The second line of development was followed by other algæ, and the method proved so efficient that it became the dominant one in the plant kingdom. Among these algæ there occurred a differentiation of the zoospores. The first step in this differentiation was an increase in size of one of the sex cells, so that they differed both in action and in form. To distinguish one from the other the larger sex cell is called the female cell, or egg, and the smaller, the male cell, or sperm. A further difference arose in the com-

plete loss of motility by the female cell (fig. 304). When these differences exist in the sex cells their union is no longer called conjugation, but fertilization, the active male cell being said to fertilize the quiescent female cell.

377. Sex organs.—A further stage in the development of sexuality is reached when the cells producing the sperms or

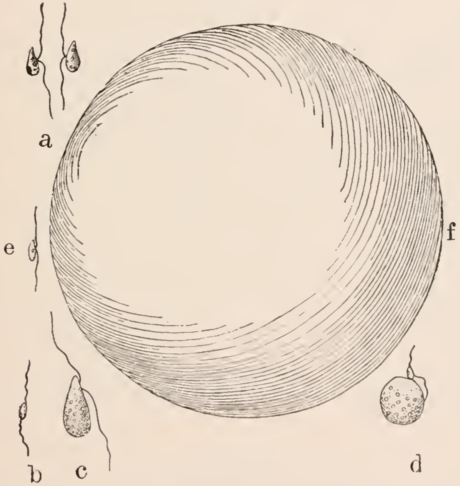


Fig. 304.—Differentiation of gametes in some marine algæ. *a*, like gametes of Ectocarpus. *b*, sperm, *c*, egg of *Zanardinia*. The egg loses its cilia and rounds itself before fertilization which is about to occur in *d*. *e*, sperm, *f*, egg of *Fucus*. This is the extreme of difference in size in gametes. All magnified equally (about 700 diam.). —After Möbius.

the eggs are differentiated. The cell or the organ producing the egg has been known by various names in different groups of plants. An appropriate general name for it, without reference to its structure, is the ovary. (See further ¶ 335.)

The male organ was called the antheridium, from the idea that it was like the anther of seed-plants, which was once supposed to be the male organ of the flower. There is no special objection to the name, but a more appropriate one for it is the *spermary*, since these male cells are known as the spermatozoids or, briefly, the sperms.

The final step in the development of sexuality is the restriction of the formation of sex organs to a certain phase in the life history of the plant, which is therefore known as the *sexual* phase, or gametophyte, the remaining phase or phases being called, for the sake of distinction, *non-sexual*, and constituting the sporophyte. The gametophyte alternates with the sporophyte, giving rise to the phenomenon known as the "alternation of generations." (See ¶ 55.)

378. Directive agents.—To secure the union of the male and female cells, the male gamete must be directed to the female. By what means this is accomplished is not fully known. Organic acids and sugar exercise such an influence on certain sperms that they swim towards the source of these substances. The wide distribution of such compounds suggests that probably their presence in the female gamete may render it attractive. If this is true, the sperms exhibit a special irritability towards these materials, whose diffusion acts as a stimulus.

Isogamy.

Sexual reproduction, as developed among existing plants, shows two main types, known as *isogamy* and *heterogamy*.

379. Isogamy is that mode of sexual union in which the size and form of the gametes is alike. In some cases the behavior also of both male and female is alike, while in others the male shows a greater power of movement. When both are equally motile and escape from the cell, conjugation occurs wherever they happen to come in contact. The form is usually

pear-like (*E*, fig. 301). The protoplasm at the narrower end is more transparent and bears two or more cilia; while the larger end is occupied by the reserve food and particularly the chloroplasts, if present. Union of free motile gametes occurs by gradual coalescence, beginning at the pointed, transparent end (*F*, fig. 301). When the conjugation is complete the resulting spore (zygote) usually acquires a spherical form, soon secretes about itself a wall, and either begins to grow at once into a new plant or thickens the wall and becomes dormant for a time as a resting spore. In other cases the form of the gametes is determined only by the shape of the cell, from which they do not escape. The entire cell contents constitutes the gamete (figs. 303, 304). In such plants both gametes may be equally motile and meet in a branch, the conjugating tube, to form a spore, as in *Mesocarpus* (fig. 304); or the male gamete may be motile and migrate from the cell in which it is produced, through the conjugating tube into the cell containing the female gamete, with which it fuses, as in *Spirogyra* (fig. 303).

FIG. 305.—Conjugation of *Mesocarpus*. The contents of the two upper cells are accumulating in the conjugating tube to form a zygote, which is complete in the lower tube. Magnified about 150 diam. —After DeBary.

The spore thus formed may be a resting spore, in which case it secretes about itself a thick wall, and remains dormant for several weeks or months. In the plants just referred to, the spores, formed in early summer, with the remnants of the parent cell-walls about them, sink to the bottom of the water, and do not germinate till the next spring.

Heterogamy.

Heterogamy is that mode of sexual union in which the sex cells are unlike, being differentiated into sperms and eggs.

380. The sperms.—The body of the sperm is the cell nucleus, surrounded by a small amount of protoplasm which is often extended into one or more cilia (fig. 306). The more complete the differentiation of the sperm the smaller, as a rule, is the amount of body protoplasm. Whether or not the sperm is motile depends upon the conditions to which it has become adapted. Whenever motile, fertilization must occur in the presence of water of amount sufficient to permit the sperm to swim to the egg.

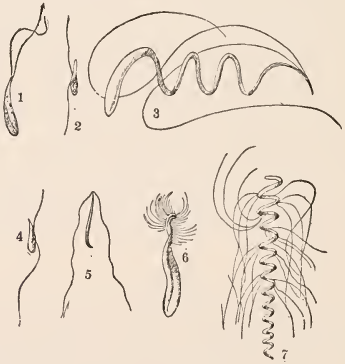


FIG. 306.—Sperms of various plants, showing variety of form. 1, *Volvox aureus;* 2, *Vaucheria synandra;* 3, *Chara fragilis;* 4, *Fucus serratus;* 5, *Marchantia polymorpha;* 6, *Equisetum Telmateia;* 7, *Marsilia vestita.* Magnified 1000 diam.—After Möbius.

The spermary may produce only one sperm (fig. 307), or its contents may divide into many (fig. 310). When single,

the form of the sperm is usually that of the cell in which it is produced. If it is set free, it may become globular, and have slow amœboid movements, or it may be entirely immotile. In the latter case it must depend upon the movements of the water into which it escapes for transference to the vicinity of the egg. The sperm may be ovoid and furnished at the end with one or more cilia; or elongated and bent or coiled one or more times. The elongated forms have almost invariably two to many cilia (fig. 306).

381. The spermary.—The organ in which the sperms are produced is the spermary or antheridium. It is either simple or compound. A *simple spermary* consists of a single cell whose contents is transformed into one or more sperms. Simple spermaries occur only in algæ and fungi, and by reduction among seed-plants. (See ¶ 385.) If more than one sperm is to be formed, the nucleus, originally single, becomes divided into as many parts as there are to be sperms (sometimes into more than become mature). The total number of sperms produced by a plant is related somewhat to the number of eggs, but particularly to the chances of the sperms reaching the egg.

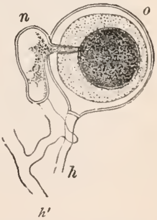


FIG. 307.—The sex organs of *Peronospora*. *h*, hypha which has developed at the end the ovary, *o*, containing a single egg (the central dark sphere). *h'*, hypha which has developed the spermary, *n*, whose protoplasm, constituting a single sperm, is passing through the fertilizing tube (a branch of the spermary) into the egg. Magnified 350 diam.—After DeBary.

If there is but a single sperm formed by each spermary, either the number of spermaries is great or some adaptation exists for the certain transfer of the sperm to the egg. In *Cystopus* and its allies, for instance, a branch of the spermary grows into the ovary, through which the sperm passes to the egg (fig. 307).

A simple spermary arises either by the differentiation of one of the ordinary cells, or of a special lateral branch, as in

the filamentous algæ and fungi (figs. 307, 308). In the thallus of multicellular algæ it may be the terminal cell of a

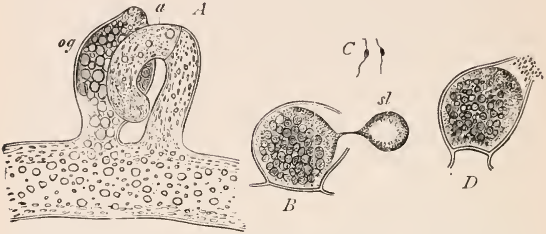


FIG. 308.—Sex organs of water flannel (*Vaucheria sessilis*). *A*, a portion of filament with two lateral branches, *a*, *og*. In *a* the spermary has already been divided from the body cavity by a partition wall. In *og*, a partition will form at juncture with main axis (see fig. *B*), when *og* becomes the ovary. *B*, the ovary, mature, having opened and extruded *sl*, a portion of the protoplasm. What remains is the egg. The chloroplasts have accumulated, leaving a clear receptive spot opposite entrance of ovary. *C*, sperms, which escape at maturity from *A*, *a*. *D*, ovary with egg about to be fertilized; the sperms have collected at the opening. *A*, *B*, *D*, magnified about 100 diam. *C*, magnified much more (about 350 diam.?). *A*, *D*, after Sachs; *B*, *C*, after Pringsheim.

branch or, in the leaf-like forms, a cluster of surface cells. In Fucus the spermaries (figs. 309, 310) are terminal cells of much-branched hairs which develop from the surface cells of a narrow-mouthed pit like

FIG. 309.

FIG. 310.

FIG. 309.—A portion of a branched hair from a conceptacle of bladder wrack (*Fucus vesiculosus*). The darker cells are the spermaries. Magnified 160 diam.—After Thuret.

FIG. 310.—Spermaries of *Fucus vesiculosus*, showing the escape of the sperms. Magnified 350 diam.—After Thuret.

that for the ovaries (fig. 326). (See also fig. 42.) The sperms are set free by the rupture of the wall of the spermary.

382. A compound spermary consists of one or more cells in which the sperms are to be produced (each corresponding to a simple spermary), surrounded by a wall formed of a single layer of cells (rarely more). Compound spermaries are found only in Characeæ, mossworts, and higher plants. The spermary is a spherical or elongated sac, raised upon a stalk, or sessile; free upon the surface of the plant, or sunk in a pit (fig. 311). The cell in which each sperm is formed

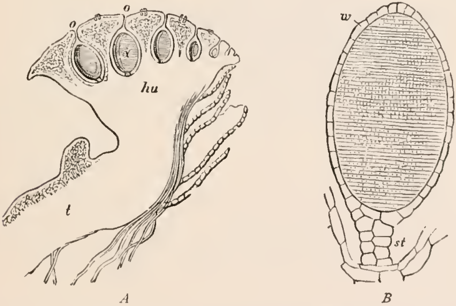


FIG. 311.—*A*, a longitudinal section ot a male head of *Marchantia*. *t*, portion of thallus; *ha*, enlarged head or receptacle; *a*, spermaries, sunk in pits opening at *o*. Magnified about 15 diam. *B*, compound spermary. *w*, its wall, surrounding the immense number of minute regularly arranged sperm mother cells; *st*, its stalk. Magnified about 80 diam.—After Sachs.

is called a "sperm mother cell." Each contains a single nucleus which enlarges to form the sperm of that cell (fig. 312). The sperms are set free by the breaking down of the walls of the mother cells at about the same time that the outer wall of the spermary is ruptured by the destruction of one or more of its cells.

The form of the vegetative body of the gametophyte in all

but the seed plants was described in Part I. The forms of the spermaries are as follows:

383. Chara.—The compound spermary of Chara (fig. 313) consists of a spherical case composed of four triangular, plate-like cells; from the inner face of each projects a handle-like cell to whose end are attached 24 filaments, each composed of 100–200 disk-shaped cells. Each of these con-

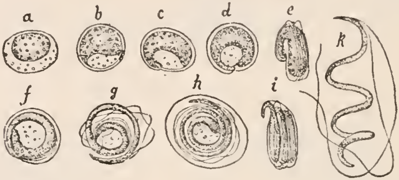


FIG. 312.—Development of a sperm of a liverwort (*Pellia epiphylla*). *a*, mother cell with nucleus, the latter approaching the wall; *b* to *h*, nucleus elongating and curving into an arc, and finally a spiral coil; *e*, an edge view, showing origin of cilia from peripheral protoplasm; *i*, also an edge view; *k*, mature sperm, free. Magnified 1000 diam.—After Guignard.

tains a sperm; so that each spermary produces 20,000–40,000 sperms.

384. Mossworts and fernworts.—In the mossworts the spermary is a stalked body, whose internal cells are the sperm mother cells, the outer layer forming the spermary wall (fig. 311).

In the fernworts the spermary is sessile and the number of mother cells is much smaller (fig. 314), corresponding to the reduction in size of the gametophyte (see ¶ 395). When the gametophyte is greatly reduced, as in the club-mosses, a single spermary only is formed, which is even larger than the rest of the gametophyte (fig. 315).

385. Seed plants.—In the seed plants the male gametophyte begins to be formed before the microspore leaves the sporangium. In gymnosperms the spore divides into two to six cells, one or two of which represent the vegetative part

of the gametophyte and the others the spermary (fig. 316). In angiosperms the vegetative part seems to have vanished and the two cells which are formed constitute the spermary, the smaller representing the sperm cells and the larger the wall cells (fig. 317; compare fig. 315). Sometimes, indeed, the smaller cell is only represented by a nucleus, no partition wall being present. Thus, the spermary in all seed plants has almost become a simple one again by reduction from the compound spermary of their ancestors. By this extreme reduction of the male gametophyte, that is, to a sex organ alone, almost all trace of resemblance to a plant has been lost, and it is difficult to think of the pollen-grain (microspore) as producing a real plant. This male plant, though extremely small and simple even when mature, is the exact homologue of the larger male plant produced by the spores of the mosses, ferns, horsetails and selaginellas.

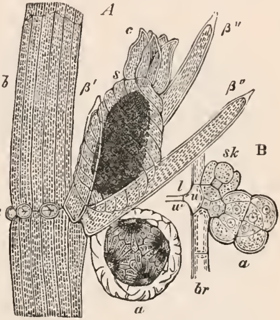


FIG. 313.—*A*, part of a "leaf" of Chara, bearing sexual organs. *b*, leaf; *β*, undeveloped "leaflets"; *β′*, leaflet; *β″*, leaflets of the branch, *sc*; the dark oval body is the ovary containing the fertilized egg; *s*, five cortical cells which have grown spirally around the ovary proper and become adherent to it; they terminate in *c*, the five crown cells, between which the sperm makes its way to the egg; *a*, the spermary, showing four of the 8 toothed plates of which its wall is composed, and the center of each to which on the inside the handle cell is attached. Magnified 33 diam. *B*, longitudinal section through young "node" of a "leaf" of Chara, showing origin and young stage of sexual organs. *l* and *w* stand in the corners of the adjacent internodal cells; between them is the thin nodal cell from which arise *u* and the sexual organs *sk* and *a*; *br*, cortical cells covering *l*, *w*. *sk* is the young ovary not yet overgrown by the cortical cells at its sides. *a*, the spermary, shows four wall cells outside, from which their handle cells have just been divided; all too young to show relative sizes or shapes. Magnified 240 diam.—After Sachs.

386. Pollen tube.—The maturity of the male gametophyte is reached only after the microspore has been caught by the moist surface (fluid in the micropyle or on the stigma) pro-

vided to receive it. The wall cell remains undivided and grows to form an unseptate filament, called the "pollen tube" (figs. 317, 318, 319, 321, 322, 323). In gymno-

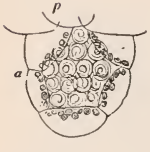


FIG. 314.

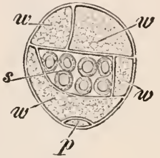


FIG. 315.

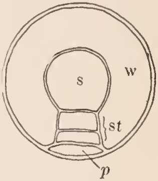


FIG. 316.

FIG. 314.—Vertical median section of the mature spermary of a fern (*Adiantum capillus-veneris*). *p*, adjacent cells of gametophyte (figs. 74, 77); *a*, spermary, showing wall composed of three cells, the two lower (above and below letter *a*) being ring-like. The chloroplasts have accumulated on the inner face. The interior cell, originally single, has divided into a number, the sperm mother cells, which at this stage are loosened and contain each a fully developed coiled sperm. Magnified 550 diam.—After Sachs

FIG. 315.—A vertical median section of the gametophyte of *Selaginella stolonifera*. *p*, a single cell representing the vegetative part of the gametophyte (compare figs. 74, 314); *w*, the cells forming the wall of the spermary; *s*, the mother cells of the sperms, each containing one sperm and now loosened from each other. The gametophyte with its single spermary scarcely exceeds the size of the microspore which produces it and therefore only just bursts the outer wall of the spore. The solution of the wall cells *w* allows the sperms to escape. Magnified 640 diam.—After Strasburger.

FIG. 316.—Diagram of the gametophyte of the larch (*Larix Europæa*), formed in the microspore. *p*, the vegetative cell; *st*, two stalk cells of the spermary; *s*, cell whose nucleus subsequently divides to form two sperms (the walls of the mother cells not forming); *w*, the wall of the spermary which remains undivided. Compare fig. 315.

sperms this penetrates the megasporangium (ovule body) and reaches the female gametophyte on whose surface are formed the ovaries (figs. 319, 320, 321, 322). In the course of its development the sperm cell loosens itself and migrates down the tube. Its nucleus is set free by the disorganization of the wall of the cell (if formed) and usually undergoes division, thus making two or more sperms (figs. 321, 322). These escape through the ruptured wall of the end of the tube, pass between the neck cells of the ovary and so fertilize the egg (¶ 393, fig. 321).

In angiosperms, in order that the sperm may reach the egg, the pollen tube must grow through the tissues of the stigma and style, or pass down the style canal to the interior

of the ovulary, then through the micropyle (fig. 323), and finally penetrate the megasporangium. The sperm nucleus then fuses with the egg nucleus (see ¶ 369).

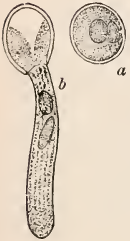


FIG. 317.

FIG. 318.

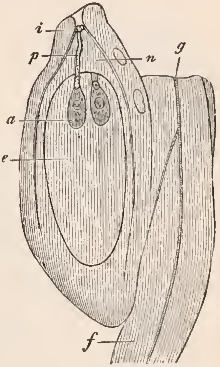


FIG. 319.

FIG. 317.—Gametophyte of the pinesap (*Monotropa Hypopitys*). *a*, microspore showing two cells; the smaller being the sperm cell and the larger corresponding to the wall of the spermary, undivided. *b*, the same, 6 hours later, showing the pollen tube developed from the larger cell. The smaller one has become disorganized and its nucleus (still undivided into sperms) and that of the larger cell have migrated into the tube. Magnified 600 diam.—After Strasburger.

FIG. 318.—One stage in the fertilization of the egg of an orchid (*Orchis latifolia*). The pollen tube, *p*, has entered the narrow micropyle, *m*, of an ovule, and reached the megaspore *e*, the upper half of which only is shown with three eggs (two imperfect). In the pollen tube, just above and below the entrance of the micropyle, are the two sperms, *s*, *s'*. Magnified 360 diam.—After Strasburger.

FIG. 319.—Longitudinal section through the ovule of the larch and the placental scale to which it is attached. *f*, placental scale; *g*, vascular bundles; *n*, megasporangium; *i*, integument; *e*, female gametophyte inside megaspore whose limit is shown by oval line; *a*, ovary; *p*, pollen-tube. Magnified 14 diam.—After Strasburger.

The growth of the spermary as a tube within which the sperms may migrate to the egg is necessary because the female gametophyte is forced to develop within the megaspore, which is not released from the sporangium. In angiosperms the further enclosure of the megasporangia in the sporophyll (carpel) makes it necessary for the tube to be sufficiently long

to traverse the pistil. Pollen tubes may, therefore, grow 10–15 cm. in length. Usually the older part of the tube dies

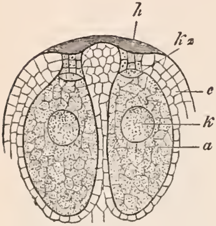


FIG. 320.

FIG. 321.

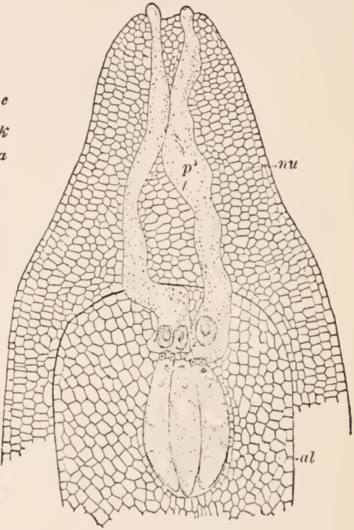


FIG. 322.

FIG. 320.—Anterior fourth of female gametophyte of spruce (*Picea excelsa*), showing two ovaries. *e*, tissue of gametophyte (endosperm); *a*, egg; *k*. nucleus of egg; *h*, neck of ovary (the line does not reach the neck, which is situated in a depression of the plant below *h*; the shading shows the side of this slope); *kz*, neck canal cell. See fig. 321. Magnified 50 diam.—After Strasburger.

FIG. 321.—A portion of the ovary of the spruce, seen as in fig. 320, but magnified 165 diam. The cell *kz* of fig. 320 has become disorganized to make way for the pollen tube, *p*, which has pushed between the neck cells and reached the egg, *e*, into which one of the sperms in its tip is about to enter. *g*, tissue of the female gametophyte.—After Strasburger.

FIG. 322. Upper part of ovule of red cedar, with integument removed. *nu*, megasporangium; *al*, female gametophyte with three ovaries of a cluster of six; *p*, pollen tube. Each ovary shows an elongated egg and above the small neck cells. The left-hand pollen tube has two sperms about to pass between neck cells into an egg. Magnified 67 diam.—After Strasburger.

as the tip advances. The food needed is chiefly derived from the cells of the stigma and style which it disorganizes.

387. The egg.—The egg is larger than the sperm, usually non-motile and fixed. In aquatic algæ the egg is sometimes

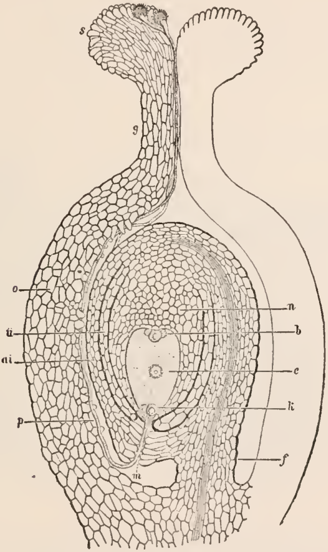


FIG. 323.—Diagram of a longitudinal section of a pistil with one ovule. *s*, stigma, on which are lodged two pollen grains; *g*, style; *o*, ovulary; *f*, *n*, *ai*, *ii*, together form the ovule; *f*, stalk; *n*, megasporangium; *ai*, outer integument; *ii*, inner integument; *e*, megaspore, with nucleus which is to develop later into vegetative part of female plant; *b*, antipodal cells; *k*, egg, and near by another; *m*, micropyle; *p*, pollen tube entering it and reaching egg.—After Luerssen.

free, escaping from the ovary in which it is produced, and being fertilized by the sperms, which are likewise free in the water, as in *Fucus* (fig. 324). Sometimes the egg itself is ciliated and hence motile. In these cases it meets the motile sperms in the water.

The form of the egg is much less variable than that of the

sperm. It is almost always ovoid or globular. The small amount of body protoplasm of the sperm may be looked upon as merely accessory. That of the egg, however, is usually abundant and well supplied with reserve food, and it takes part after fertilization in the formation of the new plant.

388. The ovary.—The organ in which the egg is produced is the ovary (oogonium, carpogonium, or archegonium). Usually but one egg is produced in each ovary, though as many as eight are formed in the Fucaceæ (fig. 327). The ovary is either simple or compound.

389. A simple ovary consists of a single cell, the bulk of whose protoplasm becomes one egg (or several).

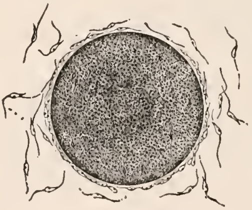


Fig. 324.

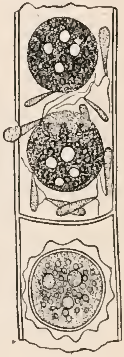


Fig. 325.

Fig. 324.—Egg of *Fucus* as it floats in sea-water, surrounded by many sperms, one of which eventually plunges into it, unites with its nucleus and so fertilizes it. Magnified 350 diam.—After Thuret.

Fig. 325.—Portion of two ovaries of an alga (*Sphæroplea annulina*). The upper part contains two eggs, and a number of sperms which have entered through the pore at the side. The lower egg of the two shows the receptive spot above. A sperm is partially imbedded in the protoplasm of this part in process of fertilization. The egg in the lower ovary has been fertilized and has secreted a thick wall, thus becoming a resting spore. Magnified 500 diam.—After Cohn.

A portion of the protoplasm of the ovary is almost invariably excluded from the egg (*B*, fig. 308). The sperms reach the egg either through an opening formed in the wall of the ovary (*D*, fig. 308, 325), or through a tube formed by the spermary, which penetrates the ovary (fig. 307).

Simple ovaries occur only in the algæ and fungi, where they are known as oogonia or carpogonia. They are either produced by the modification of one of the cells of a filament (fig. 325), or they are the terminal cell of a special branch (fig. 308). Usually the ovary is decidedly larger than the ordinary vegetative cells. The fertilized egg often becomes a resting spore (fig. 325).

In the higher algæ, especially the marine algæ, the ovaries are often aggregated in special pits, the conceptacles, as in

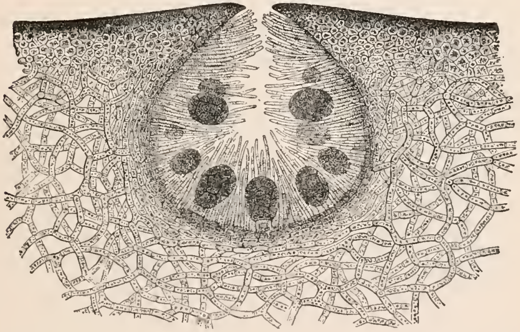


FIG. 326. A section through a female conceptacle of bladder wrack (*Fucus vesiculosus*); showing form of pit, the numerous hairs with which it is lined, and ovaries in various stages of development. In the tissue about the pit note the cortex of densely placed cells and the loose network of filaments in the interior. Magnified 50 diam.—After Thuret.

Fucus (figs. 42, 326). Here the ovary is formed by the enlargement of the terminal cell of a two-celled outgrowth from the surface (fig. 327). The eight eggs are set free and are fertilized in the water by the motile sperms (fig. 324). They grow at once into new plants.

The simple ovary is surrounded in Chara (fig. 313) by a jacket of spirally coiled cells, which grow up from beneath it and make it look as though it were compound (¶ 390).

The most highly developed simple ovary (the carpogonium) occurs in the red algæ, in which it is often differentiated into the ovary proper (which does not always form a distinct egg) and a long branch, the receptive apparatus, or trichogyne, to which the sperm adheres and through which its nucleus

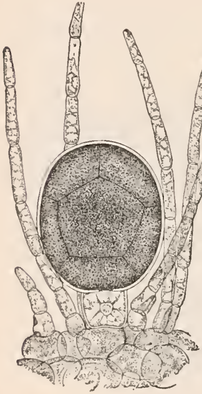


FIG. 327.

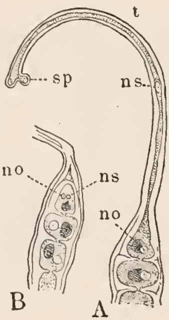


FIG. 328.

FIG. 329.

FIG. 327.—Ovary of bladder wrack (*Fucus vesiculosus*), with some of the hairs. The ovary is raised on a stalk cell; it contains 8 eggs, of which 6 are shown. Magnified 160 diam. After Thuret.

FIG. 328.—The ovary of a red alga (*Nemalion multifidum*). *A*, in process of fertilization. *no*, egg nucleus (a dark chromoplast lying near); *sp*, sperm which has adhered to the trichogyne *t* and caused the absorption of the wall there; *ns*, the sperm nucleus on the way down the trichogyne. *B*, a later stage, *no* and *ns* about to unite. Magnified about 600 diam.—After Wille.

FIG. 329.—A branch of a red seaweed (*Polysiphonia opaca*) bearing cystocarps (the black dots). See fig. 330. Natural size.—After Kützing.

travels to the ovary proper (fig. 328). The result of fertilization is the production, often by a very complicated process of growth, of a spore-producing body, the cystocarp (figs. 329, 330). The cystocarp is, in part, the homologue of the sporophyte phase of higher plants. From its interior non-

sexual spores arise (fig. 330), which produce the gametophyte again.

390. A compound ovary consists of a central row of cells (each of which is homologous with a simple ovary) surrounded

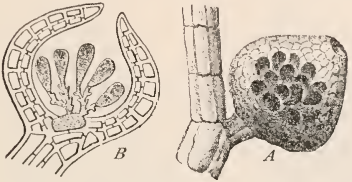


FIG. 330.—*A*, a bit of a red seaweed bearing a mature cystocarp; seen from the side. The spores show through the translucent wall. *B*, a diagram of a section through the same, showing spores as enlarged terminal cells of twigs arising from a basal cell of the cystocarp. The shaded parts arise from the fertilized egg (= a sporophyte), the case developing by induced growth. Magnified 25 diam.—After Falkenberg.

by a wall composed of one or more layers of cells. Of the central cells only the lowest produces an egg. The upper ones break down into mucilage, by the swelling of which the ovary is opened, and by its escape in whole or part a canal is formed leading to the egg (fig. 332). Down this canal the sperms make their way, and one fertilizes the egg.

The compound ovary is known as an *archegonium*. When best developed, it is a flask-shaped structure (fig. 331) consisting of a body and a neck. In the body is the cell containing the egg. Compound ovaries may be stalked, sessile, or sunk in the tissues of the gametophyte. They are found only in mossworts, fernworts, and seed plants. In the latter, however, they are simplified out of all likeness to the form described.

391. Mossworts.—When the gametophyte is differentiated into stem and leaves, as in mossworts alone, they are formed upon the stem. Usually several are developed in the same neighborhood, when they are generally protected by over-

arching leaves (fig. 331). In the same cluster there may be spermaries, or these may be on a different part of the same plant, or on another plant.

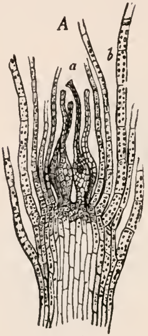


FIG 331.

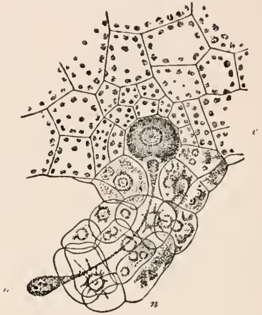


FIG. 332.

FIG. 331.—Longitudinal section through the tip of a shoot of a moss (*Funaria hygrometrica*). *st*, stem; *b*, leaves protecting the ovaries *a*. Magnified 100 diam.—After Sachs.

FIG. 332.—A vertical section of the gametophyte of a fern (*Pteris serrulata*). *g*, vegetative tissue of gametophyte, with chloroplasts; *e*, body of ovary sunk in gametophyte, surrounding the spherical egg; *n*, neck projecting and curved; *m*, mucilage formed by disorganization of canal cells and escaping, having pushed apart terminal cells of neck. Magnified 260 diam.—After Strasburger.

392. Fernworts and seed plants.—When the gametophyte is a thallus, as in fernworts and seed plants, the ovaries are borne on the surface of the thallus, partially or wholly sunk in its tissue. In the ferns, they arise upon the under surface, near the anterior end (fig. 74), and have the neck only projecting (fig. 332). In the horsetails the ovary is still more deeply sunk. In the selaginellas the gametophytes are male and female, the male arising from the microspores (fig. 315) and the female from the megaspores (fig. 333). Both are small, scarcely larger than the spores in which they grow. The ovary is completely sunk in the female gametophyte and

is much simplified, the neck-cells and the egg being the only distinct parts of maturity.

393. Gymnosperms.—In the gymnosperms the female gametophyte is not large enough to burst the megaspore which

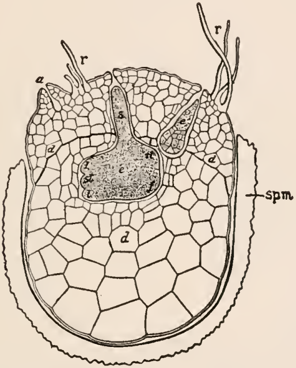


FIG. 333.—Longitudinal section of the female gametophyte of *Selaginella Martensii*. *d*, *d*, *d*, the body of gametophyte; *r*, *r*, rhizoids (rudimentary) on its surface; *a*, an ovary whose egg failed of fertilization; *e*, embryo developed from fertilized egg; its cell-structure is not shown, but the various members are begun; *s*, suspensor; *st*, stem; *l*, *l*, primary leaves; *rt*, root; *f*, foot; *e'*, a younger embryo, with cell-structure shown, the letter standing in large suspensor cell; *spm*, wall of megaspore. Magnified 125 diam.—After Pfeffer.

remains enclosed in the sporangium. Upon its surface are formed several ovaries, each reduced to an egg and two to four tiers of neck-cells (figs. 320, 321).

394. Angiosperms.—In the angiosperms the female gametophyte is so simplified that it is represented only by a few cells, among which may be recognized at least one egg (*e*, fig. 334), and possibly two others, *s*, *s*. The ovary has been reduced to nothing but an egg, and the full development of the gametophyte seems to be delayed until after the egg is

fertilized. In these plants, therefore, we return to a condition which is scarcely an alternation of sexual and spore-producing phases, because the sexual phase is nearly obliterated by reduction.

395. Relative size of gametophyte and sporophyte.—The accompanying diagram (fig. 335) may roughly illustrate the history of

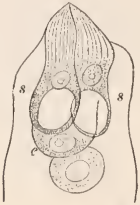


Fig. 334.

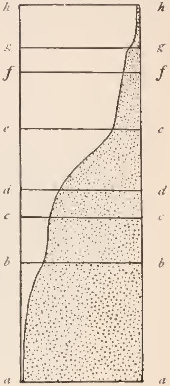


Fig. 335.

Fig. 334.—End of megaspore of *Polygonum divaricatum*. *e*, egg; *s*, *s*, synergidæ, probably sterile eggs. Below *e* the nucleus from whose divisions arise the cells of the belated gametophyte. Magnified 540 diam.—After Strasburger.

Fig. 335.—Diagram representing the reduction of gametophyte and increase in sporophyte from lower to higher plants. *a*, green algæ; *b*, red algæ; *c*, liverworts; *d*, mosses; *e*, ferns; *f*, club-mosses; *g*, gymnosperms; *h*, angiosperms. Original.

development of these phases in the vegetable kingdom.

The gametophyte phase is represented by the dotted area. It has its greatest development in the lower algæ and fungi, where it constitutes the whole, diminishes at first slowly and then rapidly. After the fernworts are passed it constitutes a relatively inconsiderable part of the plant and almost disappears among angiosperms. Of the sporophyte, represented by the white area, the reverse is true. The lines crossing the diagram at various levels show by their length in the white and black areas the relative importance of the two phases in the groups indicated.

Loss of sexuality.

396. Among fungi.—Though descended from ancestors possessing sexual organs, certain groups of plants have lost this mode of reproduction and rely wholly upon non-sexual methods. Such are the higher fungi. The lower forms only have sexual organs. These fungi show their relation to algæ by retaining in part or wholly aquatic habits. In *Cystopus*, for example, at a certain stage zoospores are produced; and these are generally characteristic of aquatic plants, though *Cystopus* has become a parasite upon land plants. Many aquatic fungi are known, most of which grow upon dead plants or animals (especially insects) which have fallen into the water. Not only do many of these lower forms produce zoospores, but the form of their sex-organs and mode of union remind one immediately of similar structure and action in common algæ. Compare, for example, the sex-organs in *Vaucheria* (fig. 308) and those of *Achlya* (fig. 336).

FIG. 336.—*A*. Functionless sex-organs of a fungus (*Achlya lignicola*). Ovaries globular, with 2-4 eggs; spermaries from branches of same hypha form fertilizing tube which remains closed. *B*, eggs which have become resting spores without fertilization. Magnified 265 diam.—After Sachs.

Some fungi possess sex-organs which are functionless, although the egg develops as though it had been fertilized (fig. 336). But in most, all trace of sexual organs has disappeared, though many produce spore-bearing structures, the fructifica-

tions (¶ 314) which are homologous with those known to arise from the fertilized egg and adjacent parts. In all these cases the fructification may be considered the homologue of the sporophyte of higher plants, for, even though its origin is now purely vegetative, this has come about by reduction from more perfect ancestors.

397. Apogamy.—In certain of the higher plants sexual reproduction is sometimes replaced by a process of budding, which differs from reproduction by brood buds (¶ 361 ff.) in giving rise to the other phase from that on which the bud arises. Some ferns, for example, regularly produce upon the gametophyte a bud which grows into a sporophyte, the sex-organs being functionless. This process is called apogamy.

398. Polyembryony.—Among the seed-plants a budding of the megasporangium, instead of the fertilization of the egg, may produce an embryo. Except that the embryo so produced suspends its growth and becomes a part of a seed, such reproduction is in no way different from that by brood buds (¶ 361 ff.) It is common in the orange, and often results in the formation of more than one embryo in the seed.

Results of sexual union.

The immediate result of the coalescence of a male and a female gamete is the formation of a cell capable of producing a new plant, i.e , a spore. The first step toward this is the formation of a wall about the spore. It may then grow at once into a new plant, or it may remain dormant for a longer or shorter time.

399. Resting spores.—In the latter case it is called a "resting spore." To protect itself, it thickens its wall, often very greatly. It may then escape from the parent by the breaking of the ovary in which it lies, but more commonly it remains enclosed until set free by the death of the parent

and the decay of the ovary. Such are the resting spores of *Spirogyra*, *Mucor*, *Cystopus*, and *Chara*.*

400. Embryo.—In the other case the sexually produced spore develops at once. Except in the brown seaweeds, whose eggs are ejected into the water before fertilization, the spore remains enclosed in the ovary, within which it begins to form an embryo.

401. Induced growth.—As a consequence of this development, growth is induced in the ovary itself and the parts adjacent. In the mildews the ovary produces one or more asci (fig. 224), while the hyphæ near by branch profusely and cover the developing internal parts with a thick false tissue (figs. 223, 337), the whole constituting a fructification. In

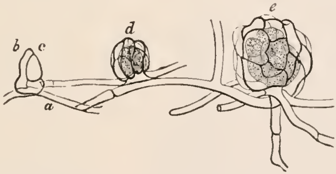


FIG. 337.—Formation of the "fruit" in a mildew (*Erysiphe Cichoriacearum*). *a*, threads of mycelium; *b*, spermary; *c*, ovary; *d*, the ovary after fertilization, showing the branches from hypha beneath ovary covering it; *e*, later stage, showing these branches coalescent and dividing by partitions to form a false tissue. (Compare fig. 223.) Highly magnified.—After Œrsted.

red seaweeds the ovary and adjacent parts finally form the cystocarp (fig. 330). In mosses the ovary grows extensively (fig. 338), but is finally torn loose and carried up on the embryo and becomes the loose hood, which is usually lost early. The stem also enlarges beneath the ovary and forms a sheath around the embryo (fig. 338), which grows downward into the parent though not organically connected with

* It should be remembered that thick-walled "resting spores" are also formed vegetatively. See ¶ 308.

it. At the same time the neighboring leaves are stimulated to increased growth.

In fernworts the sexual plant is stimulated by the growth of the embryo within it, and enlarges considerably. But it is soon outgrown by the young sporophyte, to which it supplies nourishment until leaves are produced and it is able to feed itself (figs. 76, 77, 78).

402. Seed.—In all but the seed plants the development of the embryo is uninterrupted until a mature sporophyte is formed. In seed-plants the embryo develops to a certain stage, and then

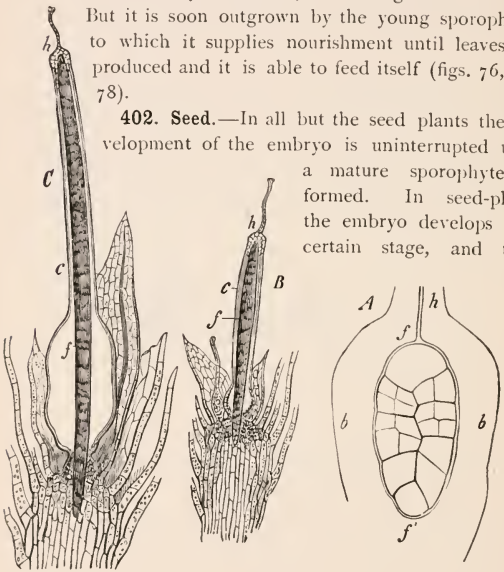


FIG 338. Development of the embryo sporophyte of a moss (*Funaria hygrometrica*). *A*, longitudinal section of the ovary, *b*, *b*, *h*, shortly after fertilization of egg which has developed into the embryo, of which *f* is the apical growing point and *f'* the basal, or foot; *b*, *b*, body of ovary; *h*, the base of the neck. *B*, longitudinal section through apex of stem and leaves. Two ovaries are seen; one has failed of fertilization; the other, *c*, has enlarged to accommodate the embryo, *f*, developing inside it; *h*, its neck, now withered. *C*, longitudinal section of same, older; *f*, the embryo has grown downward into the apex of stem; the ovary, *c*, has still further enlarged and indeed outgrown the embryo, forming a bladdery case around its base and elsewhere a close sheath for it; *h*, the neck. Around the embryo, where it enters the stem, the latter has grown up as a sheath to whose edge the base of ovary is still attached. A little later the ovary will be torn off at this point and will be lifted on the elongating sporophyte as a dry membranous sheath, the calyptra. *A*, magnified 500 diam.; *B* and *C* about 65 diam.—After Sachs.

ceases to grow. With suitable protection and food-supply it is then cast off as a *seed* (see further ¶ 408), and usually after a dormant period continues its development until mature.

403. In gymnosperms.—The growth of the embryo from the egg in the gymnosperms stimulates the whole gametophyte. This grows as rapidly as the embryo, which pushes its way into it and remains completely surrounded by it (fig. 339). The whole ovule is also stimulated to growth. The sporangium increases for a time, but is so crowded between the growing gametophyte within and the hardening integument without that it is mostly absorbed (fig. 339). The integument grows for a time to accommodate the structures within, but its tissues finally become in whole or in part thick-walled, forming the seed-coat. In a few gymnosperms (*Cycas*) its

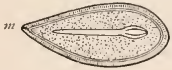


FIG. 339.

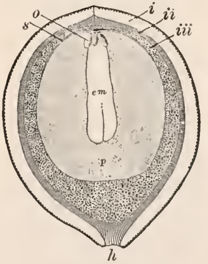


FIG. 340.

FIG. 339.—Longitudinal section of the seed of silver fir (*Abies pectinata*), showing straight embryo with several primary leaves in center of the endosperm (dotted); *m*, the micropyle. The integument has become the testa (shaded with radial lines). Between the testa and endosperm are the remains of the sporangium. Magnified about 5 diam.—After Kerner.

FIG. 340.—Longitudinal section of seed of *Cycas circinalis*. *h*, hilum (scar of attachment); *m*, micropyle; *i*, outer fleshy layer of integument; *ii* and *iii*, two hard layers of same; *s*, thin cap-like remnant of sporangium; *p*, gametophyte enlarged forming the endosperm; *o*, eggs which failed of fertilization; *em*, embryo produced by a fertilized egg. Two thirds natural size.—After Luerssen.

outer parts become fleshy, and the seed looks like a large cherry. In the yew a second fleshy integument (an aril) grows up around the hard seed (fig. 247). At maturity the seed of gymnosperms thus consists of the embryo within (fig. 340, *em*) surrounded by the gametophyte, *p*, whose cells

become filled with reserve food, constituting then the so-called *endosperm ;* around this is the remnant of the sporangium, when more than a mere membrane, likewise stored with food, and called the *perisperm ;* while over all is the hardened integument or *testa*, often of unlike layers, *i, ii, iii.*

404. Fruit.—In the conifers the sporophylls bearing the ovules and the axis from which they arise also grow. As the ovule is becoming the seed each sporophyll enlarges, but especially the placental outgrowth (see ¶ 334), and the whole number, together with the enlarged axis, form the *cone* (fig. 341, 358). Sometimes (as in the junipers) the sporophylls become fleshy and adherent, forming a berry-like body.

FIG. 341.

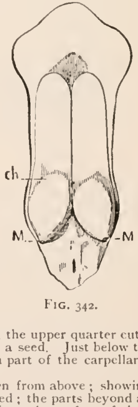


FIG. 342.

FIG. 341.—A mature cone of a pine (*Pinus sylvestris*), the upper quarter cut away. *sq*, *sq'*, the placental scales ; *g*, seeds ; *em*, embryo in a seed. Just below the placental scale which bears the lower seed *g*, may be seen part of the carpellary scale in section. Magnified about 2 diam.—From Bessey.

FIG 342.—A placental scale of pine (*P. sylvestris*) seen from above ; showing two winged seeds in place. *M*, micropyle ; *ch.* limit of seed ; the parts beyond are flat wings, formed by the splitting off of a layer of tissue from the surface of the scale. Magnified about 3 diam.—From Bessey.

When firm at maturity the cone scales open on drying, and the seeds, each with a wing attached, split off from the scale (fig. 342) and are shaken out.

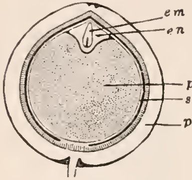
405. In angiosperms the development of the embryo stimulates the belated female plant to complete its growth, and the megaspore (embryo-sac) is soon entirely filled by it. This late-forming gametophyte is called endosperm, as in the pines.

406. Endosperm.—The growing endosperm and the embryo sporophyte, which it surrounds, crowd upon the sporangium. This may, therefore, partly or wholly disappear. If, when the full size of the endosperm is reached, the embryo continues to grow, it may crowd upon the endosperm until a part or all of it is absorbed. The embryo sooner or later passes into a resting stage and ceases to enlarge. In this dormant condition it remains for a time whose duration is chiefly determined by external conditions.

407. Food.—The tissue of the endosperm is utilized by the parent sporophyte as a storehouse of food for the use of the embryo sporophyte when it resumes growth. If the embryo displaces the endosperm, it absorbs the reserve food therein, consisting of starch, oil, or aleurone grains (¶ 236). In case any tissue belonging to the sporangium remains, this also is utilized for storage. To distinguish it from the endosperm it is called perisperm. It is only occasionally present in any amount in this group of plants.

408. The integuments of the ovule at the same time enlarge, and finally become differentiated in such fashion as to constitute the seed-coats. The ripened seed, therefore, consists of the following parts: (1) in the interior, occupying various positions and of exceedingly variable relative size, the embryo ; (2) immediately around this, the endosperm or perisperm, or both ; but either or both may be so shrunken and emptied as to be recognizable only by microscopic ex-

amination; (3) upon the exterior, one or two integuments more or less readily distinguishable from each other (figs. 343, 344, 345).



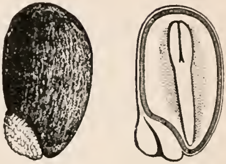


FIG. 343.—Longitudinal section of fruit of black pepper, containing a single seed. *pc*, pericarp, showing two layers (the outer unshaded, the inner shaded by radial lines); *sc*, seed-coats; *em*, embryo, surrounded by *en*, the endosperm; *p*, perisperm. Magnified about 5 diam.—After Baillon.

FIG. 344.—Seed of pansy, entire and halved, the latter showing the straight embryo, the endosperm (white and dotted), the seed-coats; *m*, micropyle. Magnified about 10 diam.—After Baillon.

FIG. 345. Seed of pokeberry (*Phytolacca decandra*), halved; showing curved embryo next the two seed-coats and nearly surrounding the endosperm. Magn. about 10 diam. — After Baillon.

409. Fruit.—The growth of the embryo excites not only the tissues of the ovule to further development, but also the sporophylls (carpels) bearing the ovules, and not infrequently even more remote parts. The carpels and their contents and adherent parts, when fully developed, constitute the fruit. The carpels are then known as the *pericarp*. The changes which the parts undergo are chiefly of two sorts—an increase in size and an alteration of texture. The increase in size requires no special explanation. The carpels may become dry at maturity, or may thicken and become soft and fleshy, or even juicy. In accordance with these differences, two sorts of fruits are recognized, namely, dry fruits and fleshy fruits. Between these, however, there is no sharp line of demarcation.

410. Dry fruits.—If the pistil contain only one or two

seeds, it very often does not open at maturity. Consequently, the seed-coats ordinarily remain thin, and the protective function is put upon the pericarp. In some cases the carpel becomes adherent at an early stage to the surface of the ovule, and at maturity the pericarp is so firmly attached that it can scarcely be distinguished from the seed-coats themselves. Such a change takes place in the fruit of most grasses, and the *grain* so formed is ordinarily mistaken for a seed (fig. 346). When dry fruits are one-seeded and indehiscent

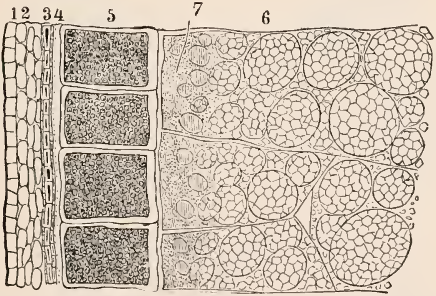


FIG. 346.—A small portion from the margin of a transverse section of grain of oats, 1, 2, pericarp; 3, seed-coats; 4, remains of the sporangium; 5–7, endosperm; 5. gluten cells; 6, cells containing large compound starch-grains (compare fig. 174) at 7 richer in gluten, with less starch. Magnified about 325 diam.—After Harz.

the pericarp usually bears whatever special contrivances are necessary for the distribution of the seeds. (See further ¶ 489 ff.) If, however, the pericarp contains many seeds, it generally breaks at maturity to allow the loosened seeds to escape. The extent and position of the opening into the seed chamber or chambers are extremely various. In some cases the openings are so small as to be mere slits or pores (fig. 347). In others a more or less circular line of breakage forms a little door or valve which opens and closes with

changes of moisture (fig. 348). In other cases the pericarp splits lengthwise into two or more pieces (fig. 349), or, less

FIG. 347.

FIG. 348.

FIG. 347.—Ripe capsules of a wintergreen (*Pyrola chlorantha*), showing dehiscence by pores. The opening is a short split at the middle of the base of each carpel. Natural size.—After Kerner.

FIG. 348. — Ripe capsules of a bellflower (*Campanula rapunculoides*), showing small reflexed valves. Natural size.—After Kerner.

FIG. 349.—*A*, capsule of violet split open at maturity, the seeds still attached to the parietal placentæ. *B*, three pods of *Lotus corniculatus*; *a*, just beginning to crack; *b*, split throughout, with the pieces somewhat twisted; *c*, empty of seeds, the two pieces fully dried and twisted. Natural size.—After Baillon.

often, cracks transversely so as to loosen a lid (fig. 350). In the former case, if it is composed of two or more carpels, (1) the carpels may separate from each other along their original line of coalescence. If these carpels so separated contain only one or two seeds, they may remain indehiscent and behave like the simple pistils previously described; but

FIG. 350.

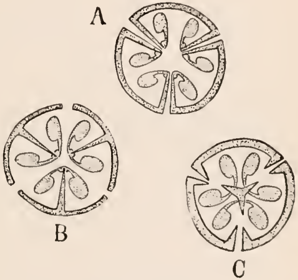


FIG. 351.

FIG. 350.—Ripe capsule of pimpernell (*Anagallis arvensis*), opening by a lid. Magnified several diam.—After Baillon.
FIG. 351.—Diagrams showing three modes in which capsules break as seen in transverse sections. *A*, septicidal dehiscence; *B*, loculicidal dehiscence; *C*, septifragal dehiscence. Modified from Prantl.

if they contain several to many seeds, they also break along their inner edges (*A*, fig. 351). Or, (2) the carpels may split along the middle, and also at the center of the ovulary if it is more than one-chambered (*B*, fig. 351; *A*, fig. 349). Or, (3) the outer parts of the carpel may split away from the placentæ, thus exposing the seeds (*C*, fig. 351).

411. Fleshy fruits.—The changes which produce fleshy fruits consist in the transformation of certain parts of the pericarp into masses of thin-walled juicy cells. Other parts may remain unchanged, or may even become hardened. The inner part of the pericarp sometimes becomes of a stony hardness, while the outer portion becomes soft and juicy. Such

changes produce a fruit like that of the peach or the cherry.

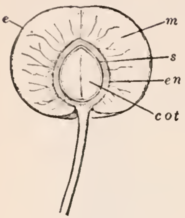


FIG. 352.—Fruit of the cherry, halved. *e*, epidermis of pericarp; *m*, fleshy layer of pericarp; *en*, stony layer of pericarp; *s*, seed; *cot*, one of the pair of thickened seed-leaves of embryo. Natural size.—After Focke.

The pericarp encloses a single seed with delicate brown seed coats whose protective function has been completely usurped by the stone (fig. 352). In other cases, while the inner face becomes stony, the outer becomes fibrous, tough, and dry, as in the almond, walnut, and hickory nut. The outer part in the last even breaks regularly into four pieces. Such fruits furnish a transition from the most perfect fleshy fruits to the dry fruits. In other cases the placentas become very much enlarged, and the whole of the pericarp becomes fleshy, as in the tomato. In others the outer part of the pericarp is hard and firm, while the inner becomes pulpy, as in the pumpkin and squash.

412. Accessory fruits.—Parts adjacent to the carpels, either flower leaves or axis or both, stimulated to growth, frequently enter into the formation of fleshy fruits. These may be accompanied by either a fleshy or a dry pericarp. In the wintergreen berry the calyx grows thick and fleshy and surrounds a dry pericarp, which cracks at maturity (fig. 353). In the strawberry (fig. 287) the torus becomes greatly enlarged and fleshy, while the minute, one-seeded, dry fruits are scattered over its surface, imitating small seeds. The fig has the same parts, with the torus concave, instead of convex (fig. 289). The apple consists of a fleshy torus carrying at its free end the withered calyx and enclosing the tough, thin

FIG. 353. — Fruit of wintergreen (*Gaultheria procumbens*), halved, showing thin (dry) pericarp, surrounded by thickened fleshy calyx. Magnified about 2 diam.—After Gray.

pericarp (fig. 354). In the blackberry the receptacle becomes fleshy, and each pistil forms a minute fruit like a

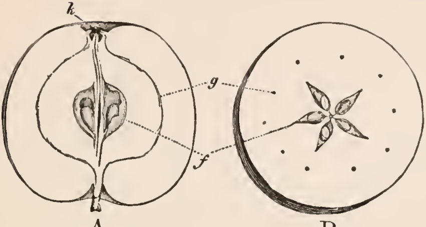


FIG. 354.—Fruit of the apple. *A*, halved longitudinally; *B*, halved transversely. *f*, pericarp, enclosing seeds; *g*, vascular bundles of the fleshy torus entering *k*, the calyx leaves. One half natural size.—After Focke.

cherry, adherent to its neighbors and to the pulpy torus. The raspberry is like it, except that the adherent mass of fruits separates as a cap from a firm torus (fig. 355).

413. Multiple fruits.—If the flowers form a crowded inflorescence, either dry or fleshy fruits may be closely crowded at maturity. Under these conditions fleshy fruits frequently become adherent, and may thus constitute a *multiple fruit* quite similar in form to the fruit formed by the aggregated

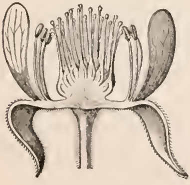


FIG. 355.

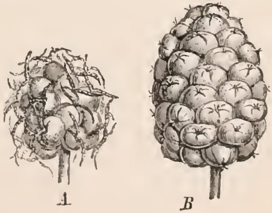


FIG. 356.

FIG. 355.—Vertical section of a flower of raspberry (*Rubus idæus*), showing numerous pistils which form the caplike fruit over the enlarged torus; stamens, corolla, and calyx all united at base. Magnified about 2 diam.—After Kerner.

FIG. 356.—*A*, pistillate flower cluster of white mulberry; *B*, multiple fruit from same. Natural size.—After Baillon.

carpels of a single flower. Compare the multiple fruit of the mulberry (each section from a separate flower whose floral leaves and pistil both become pulpy; fig. 356) with such an aggregate fruit as the blackberry, in which each section is one pistil out of the many belonging to a separate flower (fig. 355). The pineapple is similar to the mulberry in origin.

Even more remote parts are stimulated to development by fertilization of the egg. The stem bearing the flower generally grows and becomes stronger, to carry the fruit, especially if large. The minute bractlets sometimes become highly developed beneath the fruit. The cup of the acorn and the husk of the hazelnut originate in this way as the nuts form. The similar husk of the beechnut and chestnut encloses more than one fruit.

414. Distributive arrangements.—Since the seed plants abandoned the distribution of the megaspores and form both the gametophyte and the new sporophyte within the tissues of the old, it became necessary to adopt some other method whereby the young can be so scattered as to prevent them from coming into sharp competition with the parents. This distribution occurs at the time of maturity of the seed, i.e., when the embryo has become dormant, and the food store and protective coverings have been completed. The devices by which seeds are scattered are dependent upon the number and character of the seeds and the nature of the pericarp. Thus, one-seeded, indehiscent fruits must be scattered by the structures arising upon the surface of the pericarp or its adherent parts. On the contrary, seeds which escape from the pericarp have the distributive structures developed by the seed coats themselves. For distribution plants adapt themselves so as to employ the agency of the wind, water, and animals, or they develop special mechanisms for casting off the seed as a projectile. A consideration of these adaptations belongs to ecology. (See Chap. XXVI.)

PART IV: ECOLOGY.

415. Definition.—Physiology, in its broadest sense, may be divided into physiology proper and ecology. Ecology is that portion of botanical science which treats of the relations of the plant to the forces and beings of the world about it, as distinguished from physiology proper, which treats of the relation of the plant as a whole to the chemical and physical forces within it. The forces without the plant necessarily limit and modify the action of the forces within it; consequently it is quite impossible to draw a sharp distinction between those subjects which belong to ecology and those which belong to physiology proper. Parts II and IV, therefore, will be found to overlap in many places. Several of the subjects already treated under physiology belong in part to the present section. For example, the movements of plants are due not to internal causes alone, but to internal causes as modified by external conditions. In this part only a bare outline of the adaptations of plants in form and habit to their physical surroundings and to other living beings can be given.

I. NUTRITIVE ADAPTATIONS.

§ I. ADAPTATIONS OF FORM AND STRUCTURE TO ENVIRONMENT.

CHAPTER XIX.

FORMS OF VEGETATION.

416. Adaptation.—The various physical conditions which make up the "climate" of any particular region of the earth's surface, together with the nature of the substratum upon or in which the plant grows, largely control the form and functions of the plants found in that region. Stated in other words, plants, in order to exist at all, are compelled to adapt themselves to the places in which they grow. This compulsion is on pain of death.

417. The struggle for existence.—The competition between plants is intense. Only a very small portion of the seedlings which start in any particular area can come to maturity. Far the greater number will be killed by being robbed of light and of water by the overshadowing leaves and interlacing roots of their companions. Since such competition exists, it is evident that only those best suited to the conditions under which they grow will have any chance whatever to survive.

Not only are individuals subject to this competition, but all individuals of a particular kind (a species) may be destroyed in any region through the competition of other species better suited to the conditions of that region.

Through this competition between species one kind may be forced to migrate to some different region in order to maintain itself. The capacity of a plant to adapt itself to a different environment determines the possibility of its occupying a new region, for here it must come into competition with other sorts, and can only maintain itself if it is capable of so modifying its form and structure as to adapt them to the new conditions, and that as well as or better than the occupants it finds in possession. In the beginning it was probably by competition between species that water plants were gradually adapted to an amphibious life, and then to a terrestrial life, all the while advancing in complexity; later some green plants adapted themselves to a parasitic or saprophytic life; plants of moist regions gradually moved out and occupied even the deserts; plants loving the shade adapted themselves to the direct light of the sun; and so on, until all parts of the earth's surface and even considerable depths of the ocean have been occupied.

418. Environment.—In order to understand the variety of factors which are acting upon any particular plant, it will be instructive to consider the conditions which surround the ordinary land plant. A portion of such a plant is imbedded in the soil, and the remainder rises into the air. The subterranean part is profoundly influenced by the size and form of the soil particles, as well as by their chemical composition. It is exposed to contact with water varying in amount, sometimes from day to day and always from time to time during the year, holding many substances in solution in varying amounts and kinds at different periods. It is subject, also, to variations of temperature from day to day and from season to season.

The aerial part of such a plant is exposed to greater or less variations of temperature from hour to hour, from day to night, from day to day, and from season to season. It is

exposed to light varying in intensity from day to night and from day to day, and to light differing in direction from hour to hour of each day. It is enveloped by fogs or mists, or is pelted by rain, hail, sleet, or snow, and sometimes completely buried in ice or snow.

A plant has little or no power to alter any of the agents which act upon it, but it must be able to withstand the injurious ones, or even to turn them to its advantage. It would be difficult to conceive a more complex set of factors to which adjustment must be effected ; and the more since these conditions are combined with each other in an infinite variety of ways. Because the physical conditions vary in different parts of the earth's surface, the vegetation in each region differs from that in others.

In any particular locality certain conditions of water, soil, air, temperature, light, and precipitation are likely to be associated. It is possible, in a somewhat arbitrary way, to recognize four general sets of conditions to which plants must adapt themselves, in each of which the water supply is the predominant factor. It should be understood clearly, however, that these sets of conditions pass into each other imperceptibly. Corresponding to these four sets of external conditions, we may recognize certain characteristics in plant form and structure, which are likely to be associated, and it thus becomes possible to distinguish four forms of vegetation corresponding to the four sets of external conditions.

419. The first set of conditions consists of those *characterized by no extremes.* Both the air and the soil are moderately moist ; the precipitation is distributed through the year, or at least through the growing season ; there is no excess of salts in the water or in the soil ; the soil is usually enriched with organic matter, often in considerable amount. The plants which grow under these conditions are the ones most familiar to people in the fertile regions of temperate

climates. These may be reckoned as the average, or *mean*, plants, and are therefore called technically *mesophytes*.

420. A second set of conditions is characterized by *deficient water supply* throughout the year, the amount of water present in the soil often being less than 10%. Such regions may be considered as regions of continuous drought. The plants adapted to these conditions are known as drought plants, or *xerophytes*.

421. A third set of conditions, prevailing over comparatively limited regions, is characterized by an *excess of salts in the soil or water*. These salts are chiefly sodium chloride ($NaCl$, common salt), gypsum ($CaSO_4$), and magnesium chloride ($MgCl$). Plants which can live under these conditions are known as salt plants, or *halophytes*.

422. A fourth set of conditions is characterized by an *excess of water*. The plants grow wholly or partly surrounded by water, or their roots are imbedded in a soil supersaturated with water, that is, containing at least 80%. Such plants are called water plants, or *hydrophytes*.

It will be noticed that the first three groups, namely, mesophytes, xerophytes, and halophytes, are essentially *land plants* in distinction from the fourth group, which are *water plants*.

CHAPTER XX.

MESOPHYTES.

423. I. Mesophytes show certain general relations to external conditions, many of which are also shared by other forms. Except to these minor variations in the environment, they show no special adaptations; or, rather, they are looked upon as the normal plants, and the ways in which others differ from them are spoken of as special adaptations. In reality, however, the general methods by which they adapt themselves to their environment, which are now to be considered, are quite as much special adaptations as those shown by plants living in extreme climates. These adaptations will be discussed in relation to each of the main factors of the environment.

424. 1. **Air.**—The *composition* of the air varies little from place to place. It is only in those regions in which it is rendered impure by artificial means, such as the vicinity of cities and factories, and in the few isolated regions in which it is vitiated by natural means, as in volcanic regions, that any special adjustments may be looked for. Artificial vitiation of the air kills off certain plants. A few plants have adapted themselves to air in the neighborhood of fumaroles, where they are subjected to vapors containing large amounts of sulphurous acid. Whatever special adaptations are found are internal, since only the very simplest plants find it possible to live in such conditions.

The *movements* of the air, however, influence profoundly

the form of plants. This they do indirectly by the shifting of sands in sandy regions, and by their effect upon the precipitation and upon the moisture of the atmosphere. Winds increase evaporation from the soil and from the surface of plants, and thus directly influence form. Trees growing in wind-swept regions are always low, bushy-branched, with the trunk and limbs inclined to leeward. The twigs on the windward side are often dead. Forests in wind-swept regions often thin out to windward, the trees becoming smaller and smaller, finally being replaced by bushes which become sparser until no woody vegetation is present. The leaves upon such plants are small and often peculiarly spotted. These effects upon the form have been ascribed to the mechanical action of the air, to the presence of salts when in the neighborhood of the ocean or salt lakes, and to the reduced temperature; but probably none of these causes is to be looked upon as so efficient as the drying brought about by the prevalent wind.

425. 2. **Light.**—Light affects plants directly through its influence upon their nutrition and upon the evaporation of water from their surfaces. In this way it affects (1) the *rate* of development. For example, the blossoming of flowers and the production of leaves occur earlier upon the sunward side of a tree or shrub than upon the other side. In the same cultivated crops of the north and south there will often be several days' difference in the total number between sowing and maturing. Thus barley at northern Norway, in 68° N. lat., matures in 89 days, while at Schonen, in 56° N. lat., it matures in 100 days. Since the total hours of illumination must be about equal, the longer days of the north enable the plants to produce more food, and so to mature more rapidly. The forcing of vegetables under glass by the aid of electric light during the night depends upon the same principle. (2) The *form* of plant parts is directly influenced by light. Plants accus-

tomed to the direct sunlight and those accustomed to shade show profound differences in habit. Light plants are stocky and compact; their stems are inclined to be woody, the leaves are usually folded or crisped and often set at an acute angle with the direction of the light, and the surfaces are frequently hairy. In contrast, shade plants are slender and sprawling; their stems often thin and weak; the leaves flat and smooth and set transverse to the direction of the light-rays, while the surface is slightly, if at all, hairy. (3) In *internal structure*, also, there are decided differences, particularly in the leaves. (See ¶ 167, 438.) The leaves of light plants usually have a thick epidermis, often shiny, with lateral walls straight; the stomata are frequently confined to the under side and often sunk; the palisade cells are elongated, sometimes forming two or three layers and occasionally appearing on both faces of the leaf. The shade plants, on the contrary, have a thin epidermis, often containing chlorophyll, with lateral walls often very wavy; the stomata are produced on both sides of the leaves, and the palisade tissues are poorly developed. Light plants frequently have red cell-sap, especially in the epidermis of smooth plants, and their colors are always deeper, especially in the plants of high latitudes. Shade plants, on the other hand, are usually pale, rarely high-colored.

426. 3. **Temperature.** — Temperature exercises an important influence upon plants, both upon their aerial and subterranean parts. The temperature of the air is really much more important in controlling the adaptations, and consequently the geographic distribution, of plants than is light. The reason for this is to be found in the much more unequal distribution of temperature in various regions of the earth's surface. Moreover, temperature affects every vital function of the plant, for each of which a maximum, minimum, and optimum point may be determined. (See ¶ 186, 263.) The

variations in temperature to which plants are subjected require special adaptations.

427. (*a*) **Protection against changes of temperature.**— These adaptations are to be found in the presence of special cell-contents, such as oils or resins, which reduce the liability of those cells to freezing ; in the reduction of the amount of water in cells so that less damage results from freezing ; and, finally, in the presence of poor conductors of heat, such as scale-leaves and hairs in profusion, a jacket of old withered leaves, etc., all of which insure slow thawing if the plant is frozen. The winter buds of trees in temperate climates illustrate all of these adaptations.

428. (*b*) **A dormant period** is necessitated by low temperature during part of the year in temperate and arctic climates. The period of vegetation in the higher latitudes is often very short. The same conditions prevail at high altitudes, with the same effects. In these regions, therefore, the plants are almost all perennials. In many cases the rudiments of flowers are formed in the year preceding that in which they are developed, in order that full opportunity may be given for the ripening of the seeds and fruits in the short growing season. Some plants adapt themselves to short periods of vegetation by the presence of evergreen leaves, which are ready at the first opportunity to resume their work of food manufacture.

429. (*c*) **The form of plants** is modified by the temperature of the air and soil. Low temperatures are also likely to bring about the formation of dwarf plants.

430. (*d* **The rate of development** is strikingly influenced by variations in the temperature of the soil. The soil heat is derived from the sun and from the decomposition of organic matter within it. The sun is far the most important source. The amount of heat absorbed varies with the exposure of the soil, its color, porosity, amount of water, and the duration of

the sun's rays. The influence of the temperature of the soil is mainly indirect, acting through its effect on the water supply of the plant.

431. (*e*) **Moisture and precipitation.**—The amount of *moisture* in the atmosphere largely determines the amount of evaporation from the surface of the plant. The relative amount of moisture in the atmosphere is exceedingly variable, and bears a direct relation to its temperature. Indeed, so closely related are the conditions of temperature, light, and moisture in the air, that the adaptations of shade plants, mentioned above, may be considered as the sum of the effects due to these three factors. It is difficult, if not impossible at present, to say which are the effects of light and which of evaporation.

Precipitation affects plants chiefly as it influences water supply. A few plants only of the higher forms are able to absorb moisture directly from the air, except as a last resort. (See ¶ 196.) Many of the lower plants, such as the algæ, lichens, and mosses, absorb rain instantly by their aerial parts. Some plants have adapted themselves to frequent and prolonged rainfall, bearing it often for months at a time; other plants under such conditions lose their leaves very quickly. Rain-loving plants have their leaves furnished with elongated tips or with grooves and hairs to carry off the rain quickly. Their surfaces, also, are not readily wetted by water. Others protect themselves against the rain by adjusting the direction of their leaves to it so that a heavy, splashing rain strikes them at an acute angle. Others, by a movement of their leaves as soon as the sky is clouded, avoid injury from heavy rains. The branching of leaves in certain cases may be looked upon as a protection against heavy rainfall.

The snow cover through cold periods is for many plants essential as a protection against low temperatures during the dormant period. Others have adapted themselves to growing

even in the midst of snow, putting forth their leaves and blossoms while still surrounded by melting snow.

432. (*f*) **Soil.**—Both the chemical composition and the physical properties of the soil affect plants. The latter are, however, by far the most important. Here, again, the reason is to be found in the relation of the physical qualities of soil to the water supply.

The water which permeates the soil takes up from it certain substances, and becomes thus a dilute solution of various salts. That the salts thus present in the soil water may affect the form of the plant is strikingly shown in the occurrence of certain species of a genus only upon soils containing lime, while others of the same genus are found only in soils free from lime. When the local distribution of corresponding species of the same genus within the same region is determined by the presence or absence of lime in the soil, comparison of them indicates the general effect of lime salts upon the plant. Plants growing upon lime are usually stronger and more densely hairy, often hoary, while those on other soils are smooth or furnished with glandular hairs. The lime-loving plants have bluish-green leaves, as contrasted with the grass-green. Their leaves are also more numerous and more deeply branched, the flowers larger and their colors duller and paler.

CHAPTER XXI.

XEROPHYTES AND HALOPHYTES.

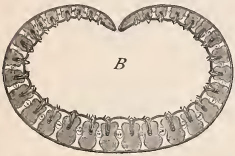
433. II. Xerophytes.—The plants of dry regions blend by imperceptible gradations with the mesophytes. They reach their best development in desert and rocky regions. Some, especially of the lower forms, grow in such situations that they must adapt themselves to become so dry at certain periods that they may be powdered. Such, for example, are a few algæ, many lichens, mosses, and a few fernworts. Adaptations in these cases must be looked for in the character of the cell contents.

Other plants must adapt themselves to endure dry periods, such as those occurring from day to day, or between the wet and dry seasons, by retaining in their bodies sufficient water to sustain life. The following are some of the chief methods by which plants adapt themselves to periodic or continuous drought.

A. Adaptations for reducing transpiration.

434. 1. **Periodic reduction of surface exposed.**—The dying away of an annual plant after forming its seed may be looked upon as an adaptation of this sort. Little evaporation occurs from the surface of the seed, which is thus adapted to withstand prolonged dryness. Perennial plants accomplish the same results when their annual shoots die off and leave only the rhizomes, tubers, and similar parts buried in the soil. Perennial plants with perennial shoots may drop their leaves

during the dry period and form them again upon the return of the growing season. The fall of leaves in our woody vegetation is a similar adaptation to the cold season. The rolling or curling of leaves is a common mode of avoiding evaporation. It is common in grasses (fig. 357) and mosses.



435. 2. **The constant reduction of exposed surface.**—This may be secured among the leaves by reducing them either in area or in number or both, or by much branching, with little green tissue.

A

FIG. 357.—Transverse sections of a grass leaf (*Lasiagrostis*). *A*, open; *B*, rolled, when dry. The white plates are the ribs of mechanical tissue above and below a stele, one in each ridge; the shaded areas are green tissue. The stomata are located low on the sides of the narrow grooves between the ridges, so that when the leaf is rolled, evaporation through them is hindered. Magnified 16 diam.—After Kerner.

Plants with bristle-shaped or needle-shaped leaves (figs. 101, 358), those with permanently rolled leaves (fig. 359), or those with scale-like leaves (fig. 109) show the various phases of such adaptations. Extreme reduction of surface is secured by suppression of leaves. In this case any further adaptation depends upon the stems, which must also provide for nutritive work. These may take the form of leaves (see § 112); or the branches may be thick, rigid, and fleshy (fig. 360); or they may be thread-like or needle-shaped, as in the asparagus (fig. 105); or the stems themselves may reduce their area by becoming fleshy and cylindrical, prismatic, or spheroidal, as in the various forms of *Cereus* and melon cactuses (fig. 110).

436. 3. **Movements of parts to reduce the illumination.**—Certain leaves are adapted to a permanent profile position, that is, with the edges turned toward the sky,

instead of the surfaces. (See ¶ 285.) Others assume a profile position when the illumination becomes too intense. These positions, by placing the leaf surface oblique to the direction of the light rays, reduce the amount of evaporation very considerably.

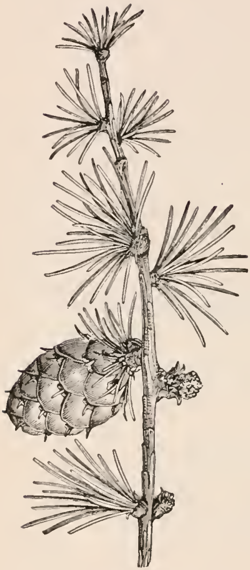


FIG. 358. — Shoot of larch, with ripe cone; showing needle-shaped leaves on dwarf branches; scale leaves on main axis; carpellary scales just peeping from between placental scales of cone. Natural size.—After Kerner.

437. 4 **Coverings,** consisting of living or dead scale-leaves, stipules, leaf-bases or entire leaves, reduce transpiration by obstructing the free exchange of air, or by holding water and so keeping moist the surfaces they cover.

438. 5. **Structural modifications.** — These may occur either in the epidermis or some internal tissues. (*a*) The *epidermis* may greatly reduce evaporation by the formation of hairs in such profusion as to form a cover for the surface (figs. 361–364). Hairs intended to protect from evaporation are usually dead and filled with air. Reflecting light from many points, they look white, and the surface seems hoary, or woolly, or silky. Hairs in the form of scales which overlap reduce the rate of evaporation by covering the stomata (fig. 365). Further adaptations of the epidermis are to be found in the presence of a thick cuticle ~~(fig. 367)~~; the water-proofing of the whole of the outer wall of the epidermis; the develop-

ment of two or more layers of epidermal cells (fig. 370); or the excretion of wax or of varnish upon the surface of the epi-

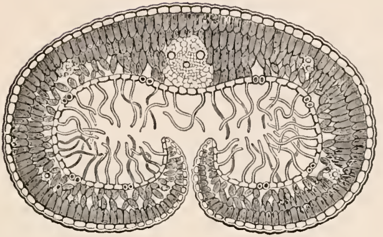


FIG. 359.—Transverse section of a leaf of a heath (*Tylanthus ericoides*), showing revolute form. The stomata are on the under (concave) surface among the hairs, which still further impede the transpiration. Magnified 130 diam.—After Kerner.

dermis. The latter often becomes very thick, giving to the leaves a shiny appearance. Wax is usually in the form of a

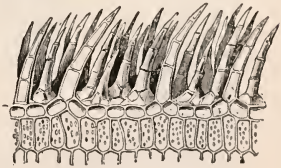


FIG. 361.

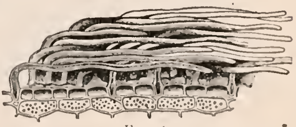


FIG. 360.

FIG. 362.

FIG. 360.—Prickly pear (*Opuntia vulgaris*) with flattened jointed stem and no leaves. About one fourth natural size.—After Frank.
FIG. 361.—Multicellular hairs of edelweiss. Magnified about 50 diam.—After Kerner.
FIG. 362.—Silky unicellular hairs of *Convolvulus Cneorum*. Magnified about 50 diam.—After Kerner.

bluish-white powder, which can be readily wiped off with the fingers, as from the surface of fruits, such as plums or grapes, the leaf of cabbage, or the stalk of sugar-cane (fig. 366). The interior layers of the wall of the epidermis are sometimes converted into mucilage, which retards the evaporation of water. The sinking of the stomata below the general

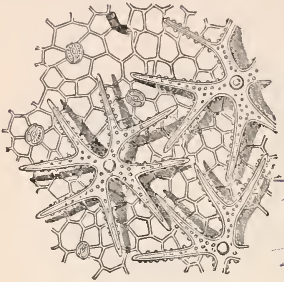


FIG. 363.

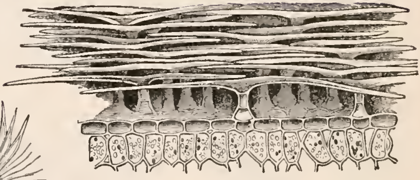


FIG. 364.

FIG. 365

FIG. 363.—Stellate hairs of *Draba Thomasii*, seen from above. Magnified about 50 diam. — After Kerner.

FIG. 364.—T-shaped hairs of *Artemisia mutellina*. Magnified about 50 diam.—After Kerner.

FIG. 365.—Shieldlike scales of an oleaster (*Elæagnus angustifolia*), seen from above. Magnified about 50 diam.—After Kerner.

level (fig. 367), their arrangement in pits (fig. 368) or in grooves (fig. 357), and their restriction to the under side of the leaf (fig. 359) may be looked upon as further epidermal

adaptations to reduce evaporation. In the leaves of some xerophytes the guard cells of the stomata are motile only when young, becoming thick-walled and fixed when the leaf is mature. The stoma itself sometimes becomes closed, also.

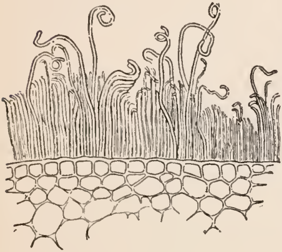


Fig. 366.

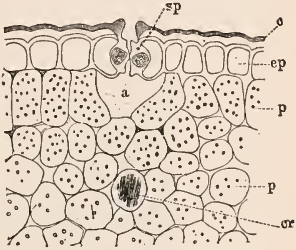


Fig. 367.

Fig. 366.—Portion of a transverse section through a node of sugar-cane, showing rods of wax secreted by the epidermis. Magnified 142 diam.—After De Bary.
Fig. 367.—Transverse section of a portion of the margin of a leaf of *Aloe socotrina*. *c*, thick cuticle; below *c*, cutinized layers of wall of epidermis, *ep*; *p*, parenchyma cells with chloroplasts; *cr*, a crystal cell with needle crystals of oxalate of lime; *sp*, guard cells of stoma, sunk below surface; *a*, intercellular space under stoma. Magnified about 175 diam.—After Tschirch.

(*b*) The *internal tissues* of the leaves may be more compact. This reduces transpiration by restricting the area of the air passages. Such dense structure is secured by multiplying the number of the palisade layers and by the more regular form of the spongy parenchyma (fig. 359 and ¶ 167).

B. Adaptations for taking up water.

439. Absorption.—1. Some plants are adapted to immediate absorption of moisture in the air or of liquid water falling on their aerial parts. Such are, usually, the algæ, lichens, and mosses which grow in exposed situations. 2. Certain of the higher plants are furnished with hairs adapted to the prompt absorption of rain or dew, e.g., Spanish

moss. 3. Other plants adapt aerial roots to the absorption of moisture from the air, as well as falling water. (See ¶ 196.) 4. Many are surrounded by the bases of dead leaves, which act as a sponge for absorbing water, and supply it gradually to the stem or younger leaves. Living leaves, sometimes singly, sometimes in clusters, form cuplike or tubular struc-

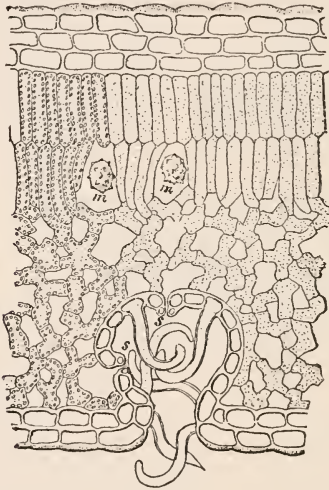


FIG. 368.—Portion of a vertical section of leaf of oleander. *ep*, epidermis of upper face; *ep'*, same of lower face with stomata, *s*, in deep pits with numerous hairs, *t*; *pal*, palisade parenchyma in two layers; *sp*, spongy parenchyma; *h*, *h'*, hypoderma adapted to water storage. Chloroplasts shown only in left-hand side of figure. Magnified about 175 diam.—After Van Tieghem.

tures, acting as water receptacles, from which it can be absorbed as required. Such adaptations occur chiefly in epiphytes. (See ¶ 454.) 5. Many xerophytes develop exceedingly long tap roots, which penetrate the soil deeply to a permanent water supply.

C. Adaptations for storing water.

440. 1. **Special cell contents.**—The simplest of these adaptations is the presence of mucilage in the cells, arising from the cell-wall or developed in the cell-sap of various parts. (See ¶ 5.) The presence of acids, tannins, and salts perhaps aids in the retention of water.

441. 2. **Water-storing tissues.**—(*a*) Fleshy plants, or *succulents*, are those which thicken their parts by the development of an unusual amount of parenchyma, which contains a large quantity of cell-sap, and usually much mucilage. These thin-walled, mucilage-containing tissues form a reservoir for the storing of water. In such plants the epidermis is very strongly water-proofed; the stems are thick, cylindrical, prismatic or spheroidal; the leaves are wanting, or they are thick and fleshy, cylindrical or broad (fig. 369), and arranged in rosettes.

(*b*) In *non-succulents*, the epidermis itself may be greatly developed as a water-storing tissue, or it may form great numbers of bladdery hairs which are richly supplied with water, as in the well-known "ice-plant," on which the hairs glisten like ice.

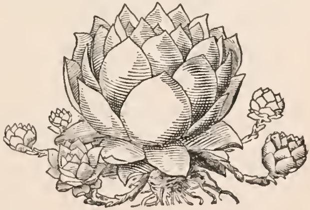


Fig. 369.—A plant of houseleek (*Sempervivum tectorum*), showing fleshy leaves arranged in a rosette, with offsets formed at the ends of special branches. These become detached and form independent plants. About one half natural size.—After Gray.

In the first case, the epidermis, instead of forming a single layer of cells, may develop into several layers, the lower ones large and thin-walled, as in begonias, figs, and peppers (fig. 370). The cells immediately under the epidermis sometimes become transformed into a water-storing tissue, as in the oleanders (fig. 368); or strips of tissue extending from the

upper to the lower side of the leaf may act as reservoirs of water.

442. 3. **Tubers and bulbs.**—These forms of the shoot in which the parenchyma is abundant and richly supplied with water may also be counted, in part at least, as an adaptation for water-storage.

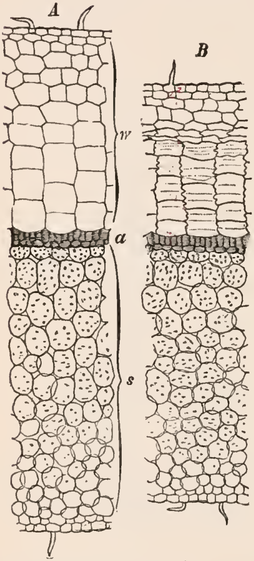


FIG 370.—Strip from a vertical section of leaf of *Peperomia trichocarpa*. *A*, from a fresh leaf; *w*, water-storing tissue, composed of the multiple epidermis of the upper side; *a*, chlorophyll-bearing cells; *s*, spongy parenchyma with sparse chloroplasts and much water. *B*, the same after four days' transpiration at 18–20° C. The tissue *w* is much collapsed, the walls being plaited; *s* also shrunken, but *a* as before. Magnified about 50 diam.—After Haberlandt.

443. III. Halophytes.—The salt-loving plants are, in most of their characters, strikingly similar to the xerophytes. This similarity is to be explained probably by the difficulty of securing a suitable water supply. They grow near the ocean, upon the shores of salt lakes, by salt springs, and in the interior of the great continents in old lake basins in which the salts have accumulated by the rains. A few of the halophytes are trees and shrubs, with leathery leaves, but almost all are succulents. In habit they are generally low, often creeping, with thick, fleshy and more or less translucent leaves and stems; the cells large and thin-walled, containing comparatively little chlorophyll and abundantly supplied with water, with few and small intercellular spaces and the surface generally smooth.

CHAPTER XXII.

HYDROPHYTES.

444. IV. Hydrophytes may be divided into three groups: 1. *Slime plants*, which grow in the mud or slime at the bottom of bodies of water. Here belong many algæ, especially diatoms, many species of low fungi, and bacteria in great numbers. 2. *Submersed plants*, either free or attached. Many algæ, including both the diatoms and the filamentous algæ, are found floating in the water at various heights, sometimes near the surface, sometimes more deeply submersed. Since their substance is heavier than water, their capacity to sustain themselves depends upon the production of gases in the interior of the cells, or upon the presence of gases entangled among their filaments. A few of the higher plants are also found submerged and free, such as the bladder-worts. The number of free-floating plants of the larger kinds is small compared with those attached. The higher algæ, moss-worts, fern-worts, and seed plants are usually fastened in the mud or to sticks and stones. The thallus of the algæ is usually profoundly branched and the shoots of the mosses are richly supplied with leaves. All of the submerged fern-worts and seed plants are characterized by a very thin-walled epidermis, the absence of stomata, and the extensive surface due to the very profuse branching of the stems or leaves, or to the great number of these, or to both. In all cases the extensive green surface may be looked upon as an adaptation to securing carbon dioxide and the manufacture of sufficient

food by means of the weak light in a situation where there is no danger from lack of water. 3. *Floating or partly submersed plants*, either free or attached. Many of the filamentous algæ and diatoms float free at the surface. The chief characteristics of the higher floating plants which root in the mud are these: their floating leaves are simple, little branched or not at all, roundish or elliptical in form, leathery, and the surface not easily wetted; stomata are present only on the upper surface, and the leaf stalks are adapted in length to the depth of the water in which they grow; the woody tissues are either entirely absent or poorly developed, because there is no occasion for the transportation of water, nor need of rigidity, since the medium in which they grow supports most of the weight.

445. Light.—Green water plants are limited in their distribution by the depth to which light can penetrate water. This does not exceed even in pure waters four or five hundred meters. No seed plants have been found at a greater depth than thirty meters, and few algæ at a greater depth than forty meters. Plants which are brought up by dredging from lower depths than this are usually those which have been detached and sunk.

446. The temperature of the water is very much less subject to variation than that of the air, never falling, except at the surface, below 0.5° C.*

447. The movements of the water are of much importance to plants in bringing air and food materials to them. These movements are wave movements, or *surf*, and *currents*. Plants growing within the limits of wave action are often damaged or torn away by the waves. The Sargasso Sea is marked by an accumulation of such plants, mainly of brown

* The minimum temperature of the deeper water is usually stated as 4° C., but many observations upon Lake Mendota by Birge have shown that in winter it falls nearly to zero, even at a depth of eighteen meters.

algæ, which have been swept to the quieter parts of the North Atlantic by currents after having been detached by the waves. Such plants may often live for a long time and may even continue their development.

Plants adapt themselves to currents, such as those in fresh-water streams, by their slender form, which is characteristic of plants in flowing waters, as seen in filamentous algæ and the much divided leaves of higher plants. Currents of water act as a stimulus upon certain plants, producing a direct reaction in the mode of growth.

448. The composition of the water affects chiefly the distribution of plants, in a manner similar to the presence of salts in the soil. In the ocean waters the percentage of salts is extremely variable in different regions; in some places it is as low as 0.5 per cent., while in others it reaches 4 per cent. In fresh waters the differences in kind and amount of dissolved salts are chiefly due to differences in the soils which the streams drain.

§ II. ADAPTATIONS TO OTHER PLANTS.

449. Plant associations.—Each set of external conditions brings about the association of certain plants with each other, because they have adapted themselves to those conditions. The four groups just considered may be looked upon as plant societies of the most general kind. Within each of these four it is possible to distinguish a number of smaller societies determined by a more limited range of conditions.

Besides these plant associations, however, there are those which are determined by the relation of the plants to each other, as affording mechanical support, or assistance in the work of nutrition. The plant associations of this kind only are now to be considered.

CHAPTER XXIII.

ADAPTATIONS TO OTHER PLANTS AS SUPPORTS.

Certain plants serve others as carriers, acting purely as mechanical supports. To these supports plants have adapted themselves in various ways. In many instances dead objects of similar form may serve the same purpose. The supported plants are, therefore, partly independent of the others, though in most instances in nature they rely upon living supports.

450. 1. **Climbing plants.** — Climbing plants are those which develop lateral organs, sensitive to contact, which become recurved or coil about a support of suitable form and

size, or form adhesive disks by means of which they cling to rough surfaces. These lateral organs are forms either of leaves or lateral shoots, and are known as tendrils (figs. 107, 156). (For their form see ¶ 115, 158; for their action, ¶ 266, 293.)

451. 2. **Clambering plants** are those which form lateral organs not sensitive to contact, and by means of them support themselves on adjacent plants. Recurved leaves, shoots, and prickles (fig. 115) may serve these purposes.

452. 3. **Twining plants** are those which have adapted their shoots to winding about a support of suitable size. (See ¶ 291.)

453. 4. **Root climbers** have adapted their aerial roots to attaching the plant to rough surfaces. (See ¶ 90.) All of these organs are structures belonging to the sporophyte, and, therefore, are found only in fernworts and seed plants.

454. 5. **Epiphytes.**—This name is rather loosely applied to those plants which are attached to others for mechanical support, and do not derive food from them. All kinds of plants have representatives in this group. Algæ, diatoms, and other small water plants attach themselves to other algæ and the higher water plants. Lichens, liverworts, mosses, ferns, orchids, bromelias, etc., are abundant upon trees. Epiphytes are attached by hair-like rhizoids, or by hold-fasts, which apply themselves to the roughnesses or even penetrate the outer dead parts, but do not absorb from the living tissues of the supporting plant either water or food materials. The water supply is provided for (1) by adaptations for absorbing rain or dew, mists, or even dampness, instantly, either by the surface, as in algæ, mosses, and lichens, or by means of hairs, as in the Spanish moss and other seed plants; (2) by adaptations to catch the water in living or dead leaves and hold it, either by capillarity or as a vessel, long after precipitation has ceased. Many of the simpler epiphytes are

adapted to become dry without injury, while the larger ones are inhabitants of moist tropical regions, where the danger of drying is avoided and it is possible to obtain an adequate water supply. Their food materials are derived entirely from the air and the water which falls upon them, while the mineral salts are obtained from the dust which has been carried by the air and accumulated upon the surface of the supporting plant, or among the mass of dead and decaying leaves and other débris about the base of the epiphyte. Organic matter from the decay of the older parts may also be reabsorbed.

An adaptation to this mode of life is marked in the reproductive bodies. Of all epiphytes the seeds or spores are either light and carried by the wind; or the seeds are sticky and carried by birds and other animals; or they are eaten by birds and voided upon the trees where they are adapted to germinate.

CHAPTER XXIV.

SYMBIOSIS.

455. Living contact.—Not only are different species associated through the influence of similar surroundings which they find congenial, but certain plants adapt themselves to such an intimate relation with others that they live in immediate contact with them. This intimate association is known as *symbiosis*. When the parties to symbiosis stand to each other in the relation of partners, each furnishing certain materials or conditions advantageous to the other, the association is called *mutualistic symbiosis* or *mutualism*. When the relation of the parties is that of master and slave, one individual deriving advantage from the labor of the other and in return furnishing it suitable conditions for existence, the association is a form of mutualism known as *helotism*. Finally, when the relation of the parties is that of an unwilling host and an unwelcome guest, one individual being fastened upon by the other from whose presence it is unable to free itself, the symbiosis is called *parasitism*. (See ¶¶ 51, 52, 53, 222.)

A. Mutualism.

456. 1. **Between plants of the same species.**—Mutualism may occur between individuals of the same species. Illustrations of this are to be seen in the massing of the lower algæ into colonies, in some of which certain individuals may be differentiated from others for the purpose of carrying on a function of advantage to the colony. (See 12, 13,

20.) In a somewhat similar way certain bacteria are found always massed into colonies, constituting a sort of thallus of

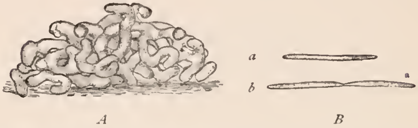


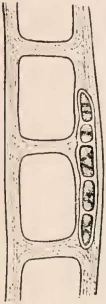
FIG. 371.—*A*, serpent-like colonies of *Chondromyces serpens*, composed of numerous rod-shaped individuals, *B*, *a*, which multiply by fission, *b*, and secrete a mass of jelly which holds them together. *A* magnified 45 diam.; *B*, 750 diam.—After Thaxter.

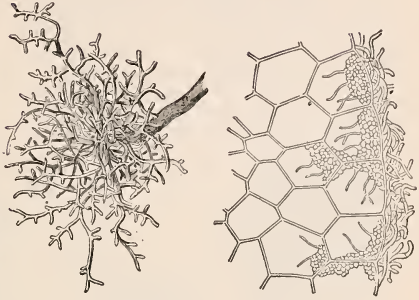
characteristic outline (fig. 371). In the higher fungi, also, the mycelium may be looked upon as a thallus formed by the aggregation of many individuals; for, while it is possible to have a mycelium produced from the development of a single spore, it is not common. The mycelium is generally the result of the union of hyphæ (see ¶ 50) arising from many spores. Even in such cases the mycelium may constitute a single body, and may give rise to a single fructification.

457. 2. **Between plants of different species.** — Mutualism is more common between plants of different species. It takes the following forms:

458. (*a*) **Lodgers.** — The higher plants often shelter various species of lower ones within their intercellular chambers, or in pockets formed by lobes or bladders of various sorts. This relation is especially common between water plants and algæ. Species of Nostoc live in the intercellular spaces of liverworts and duck-weeds, in the cortex of the roots of some land plants, and in the bladdery leaf-lobes of liverworts. Some species of the higher algæ, also, are frequently associated with other species to which they attach themselves. That they are not merely epiphytic (see ¶ 454) is shown by the fact that certain species are found only upon certain other species, while they do not grow upon other

plants which would furnish them similar external conditions (fig. 372).





A *B*

FIG. 372. FIG. 373.

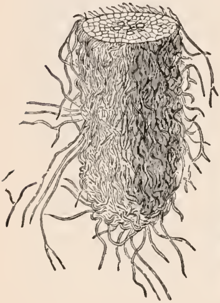
FIG. 372.—A portion of a filament of an alga (*Ectocarpus*) showing at *a* another alga (*Entoderma Wittrockii*) which has embedded itself in the cell-wall. Magnified 480 diam.—After Wille.

FIG. 373.—*A*, a tuft of rootlets of white poplar forming mycorhiza. Natural size. *B*, a portion of a transverse section of one of these rootlets, showing the mantle of fungus mycelium and the growth of the hyphæ also in some of the outer cells of the root. Magnified 480 diam.—After Kerner.

459. (*b*) **Mycorhiza.**—Mutualism between the roots of the seed plants and certain fungi is common. Such a combination of root and fungus is called a mycorhiza. The fungus forms a jacket over the outside of the root (figs. 373, 374), taking the place and work of the root hairs by means of strands of hyphæ extending from the surface of the fungus jacket (fig. 374); or it grows inside the cells of the cortex and epidermis, forming knotted masses (fig. 375); or it is confined to certain definite portions of the roots, forming upon them swellings from the size of a hazelnut to the size of a man's head. The first form is especially common upon the roots of the oak, elm, walnut, apple, pear, maple, ash, and related trees. It has also been found upon the roots of a large number of herbaceous plants. The second form belongs

chiefly to the heaths and orchids. The third form grows upon alders, bayberry, etc.

460. (*c*) **Root tubercles of Leguminosæ.**—A peculiar case of mutualism appears in the bean family between the roots and bacteria. The latter produce upon the roots small swellings from the size of a grain of wheat to that of a hazelnut (fig. 376). The presence of these



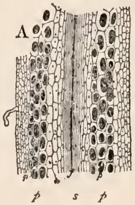


FIG. 374. FIG. 375.

FIG. 374.—Tip of a rootlet of beech (*Fagus sylvatica*) with fungus mantle, the loose hyphæ acting as absorbing organs in place of root hairs. Magnified 100 diam.—After Frank.

FIG. 375.—Mycorhiza of orchids. *A*, diagram of a longitudinal section of a root; *p*, *p*, the cells of cortex filled with hyphæ of fungus; *s*, stele. Magnified about 20 diam. *B*, a bit of longitudinal section of root of *Neottia*, near the tip. *e*, epidermis; *p*, a series of cortical cells filled with fungus. Into the cell *a* (nearer the tip of root) the hyphæ are just entering; in the cells above *i*, recently entered, they have only formed a small knot about the nucleus. Magnified about 200 diam.—After Frank.

bacteria, in a way yet unexplained, certainly enables the plant to use free nitrogen from the atmosphere, while other plants are required to obtain it in combination from the soil. The enrichment of the soil by growing clover and similar crops upon it and plowing them under is explained by their ability thus to accumulate nitrogen from the air.

461. 3. **Between plants and animals.**—Mutualism also

occurs between plants and animals. Various species of plants attach themselves to animals by which they are carried about. The plant is thus aided in obtaining the materials for food, and not infrequently the plant conceals the animal from another which seeks it as prey. In this way certain crabs are hidden by algæ attached to them. One of the most striking cases of protective mimicry is that in which an Australian fish has acquired surface outgrowths which imitate almost precisely the appearance of brown seaweeds, so that, when quiet, it looks like a stone to which seaweeds had attached themselves. Thus it often escapes its enemies, as does the crab with its mask of real seaweeds.

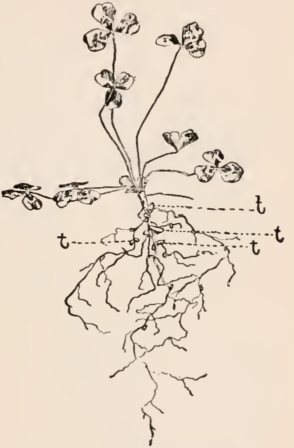


FIG. 376.—A young clover plant, showing tubercles, *t*, on the roots. Natural size.—After Goff.

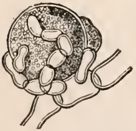


FIG. 377.—Hyphæ of a lichen, *Cladonia furcata* (see fig. 55), enveloping an alga, *Protococcus*. Magnified 950 diam.—After Kerner.

B. Helotism.

462. I. **Fungi and algæ.**—Helotism exists between fungi and algæ, constituting the bodies known as lichens, in which the fungus is the master and the alga the slave. (See ¶ 54*a*, and fig. 377.) The same fungus may be found enslaving more than one species of algæ even within the same mycelium. The protonema of mosses or even the leaves of some small

plants may be surrounded by a mycelium. The enslaved green plants are generally unicellular or filamentous algæ. If the latter are the species whose colonies produce voluminous gelatine, the texture of the lichen body is gelatinous; otherwise it is tough and leathery. Some of the fungi which ordinarily associate themselves with algæ to form lichens may exist free as saprophytes. The alga itself influences the form of the thallus more or less profoundly according to its relative amount. The same fungus associated with different algæ produces lichens which are described as different species, or even as different genera.

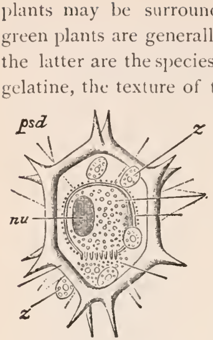


FIG. 378.—A radiolarian (*Lithocercus annularis*), one of the microscopic single-celled animals with a siliceous skeleton, *S*, formed by the outer portions of the protoplasm, *E*, which is separated from the internal protoplasm, *I*, by a perforated capsule, *c*; *nu*, nucleus; *psd*, threadlike protrusions of the protoplasm. Embedded in the outer protoplasm, *E*, are numerous "yellow cells," *z*, each with its own cell-wall, nucleus, and chloroplasts. These are an alga, called *Zooxanthella nutricola*. Highly magnified. — After Bütschli.

463. 2. **Animals and algæ.**—Helotism exists between animals and algæ. Various simple animals, such as radiolaria stentors, hydras, sponges, echinoderms, and worms, enclose algæ in their bodies and utilize the products of their food manufacture. The algæ thus enslaved are all minute unicellular forms which multiply within the animal body by division (fig. 378).

C. Parasitism.

464. 1. **Fungi.**—A very large number of colorless plants have adapted themselves to live upon living plants or animals which they force to act as their unwilling hosts. By the presence of the parasite the normal functions of the host or its normal growth or both are more or less seriously interfered with, so as to produce disease, slight or grave, local or

general, according to the circumstances. Many animals are

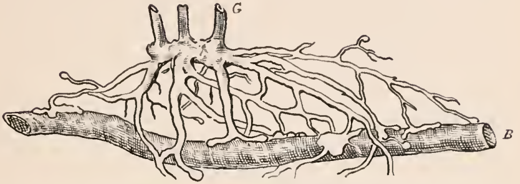


FIG. 379.—Roots of a yellow Gerardia, *G*, attached to the root of a blueberry bush, *B*. They enlarge at the points of contact and there send haustoria into the host root. Natural size.—After Gray.

thus preyed upon by bacteria and fungi. Most communicable diseases, such as typhoid fever, diphtheria, and tuber-

FIG. 380.—*A*, European dodder twining about a hop stem. All but the uppermost coils show the groups of wartlike swellings from which haustoria penetrate the host stem. Natural size. *B*, Germination of same. The various stages are arranged in order from right to left. In the last stage the seedling has found a suitable support and has absorbed all the reserve food in the thickened lower end, which has withered and died, freeing the plant from the ground. Magnified about 2 diam.—After Kerner.

culosis, are known to be due to the transfer of the parasite from the diseased individual to the healthy one. In a similar way bacteria live as parasites upon green plants, causing disease and often death. The number of bacterial diseases among plants is relatively small, for comparatively few bacteria have been able to adapt themselves to living in the acid cell-sap of plants. The number of diseases of plants due to parasitic fungi, on the contrary, is very large. (For the mode by which parasitic fungi gain entrance to the bodies of their hosts, see ¶ 52.)

465. 2. **Seed plants.**—A few seed plants have adapted themselves to a parasitic life upon others. Some may be reckoned as semi-parasitic, having still green leaves and true roots. In addition, however, special organs are developed for attaching the parasite to the roots of other plants, from which at least a water supply and probably food materials are absorbed (fig. 379). Other semi-parasites, such as the mistletoe, attach themselves to the host above ground, and have no true roots of their own. Some parasitic seed plants twine about their hosts, into which they send absorbing organs by means of which they derive all their food from the host. Such is the yellow parasitic vine, known as dodder (fig. 380, *A*). These plants germinate in the ground, and as seedlings possess true roots, but after attaching themselves to the host the lower part of the stem dies away so that the true roots are transient (fig. 380, *B*). Some root parasites begin to germinate upon the

Fig. 381.—A twig infested with a parasitic seed plant (*Apodanthes*) whose body is hidden under the bark of the host, through which a short branch bearing a few scale leaves and a single flower bursts. Natural size.—After Kerner.

ground, but do not pass beyond the first stages of development unless in contact with the root of the host by which they are normally sustained. Under these conditions they then form a cone-like enlargement, which unites with the cortex of the host root and penetrates to the stele. From this conical stem arise the aerial shoots. Other parasites form a network or even a complete hollow cylinder outside the wood of the host and under the bark. From this curious body the few flowers break through the bark and appear upon the surface of the root or stem of the host, quite as though they were a part of it (fig. 381).

§ III. ADAPTATIONS TO ANIMALS.

CHAPTER XXV.

ANIMALS AS FOOD, FOES, OR FRIENDS.

I. Carnivorous plants.

466. Nitrogen supply.—The ordinary source from which green plants obtain nitrogen for the making of their food is the nitrogen compounds dissolved in the soil water. Plants which live where the soil water contains little or no nitrogenous material are forced to resort to another source of supply. Some plants solve the problem by entrapping animals, deriving from their bodies the desired nitrogen compounds. Such plants are called carnivorous plants, or, since the bulk of their catch consists of insects, insectivorous plants. The catching of animals is done

467. I. **By pitfalls and traps.**—(*a*) *The various pitcher plants* furnish a fine example of well-devised pitfalls. The leaves of these plants have a deep, trumpetlike tube making up the body of the leaf; or they carry at the end of a long petiole a deep cup with a lid, as in the tropical pitcher plants (fig. 382; see also fig. 155). The tube is one-third or half full of water, in which are always found numbers of dead or dying insects. The sides of the tube without are often made attractive by gaudy colors or by lines of sweet secretion, which draw both flying and crawling insects. Within, its surfaces are either excessively smooth, so as to afford no

foothold to an insect attempting to crawl out; or covered by stiff, downward-pointing hairs to oppose its passage; or the side of the tube is filled with thin translucent spots through which the captives vainly strive to fly, while the real opening is concealed. By one or other of these means the prey is prevented from escaping, and sooner or later is drowned in the liquid. In this liquid digestive enzymes or bacteria quickly dissolve the softer parts of the insect bodies, and the soluble portions are absorbed by the leaf.

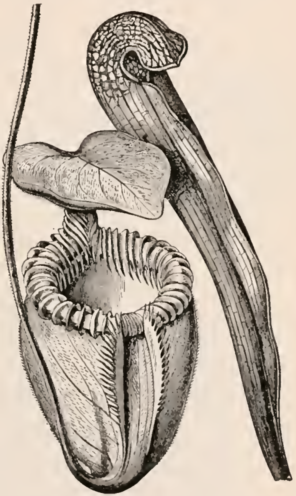


FIG. 382.—*A*, trumpet-shaped sessile leaf of *Sarracenia variolaris*, showing thin membranous windows in the meshes of the veins of the hood which arches over the mouth of the trumpet. *B*, cup-shaped petioled leaf of *Nepenthes villosa*, with elevated lid and margin ribbed. One-third natural size.—After Kerner.

(*b*) *The bladderwort*, which abounds in quiet pools, furnishes an excellent illustration of traps (figs. 383, 384). Upon the leaves are numerous minute bladders, each with a small opening about which divergent hairs serve as guides to the entrance. The entrance is lightly closed by a flap of membrane, which is readily lifted by minute water animals. After they have passed through the opening the membrane drops behind them, and is stiff enough to prevent their escape. Death ensues sooner or later, and absorbing hairs on the inner face of the trap take up the nutritive materials.

468. 2. **By adhesive surfaces.**—Animals are also captured by adhesive surfaces. These surfaces are covered by a

FIG. 383.— A bladderwort (*Utricularia Grafiana*), showing an aerial flower stalk carrying an open flower and a second one above from which the corolla has fallen. Some stems bear numerous, finely branched leaves, *b*, and others the large bladders, *b'*. See fig. 384. A shoot of a smaller species is shown at *a*, with bladders and leaves on same stem. About two-thirds natural size.—After Kerner.

sticky fluid secreted by numerous glandular hairs, and upon these many small insects may be found dead. In many

cases the softer parts of the insect bodies are digested and absorbed. It should be noted, however, that adhesive sur-

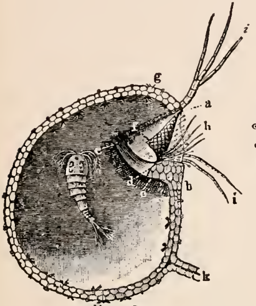
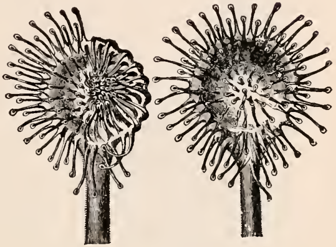


FIG. 384.



B FIG. 385. *A*

FIG. 384.—A bladder of *Utricularia vulgaris*, halved lengthwise, with an imprisoned crustacean, *Cyclops*. *a* to *b*, opening, with hairs, *h*, *i*, about it; *b* to *c*, cushion-like rim, *b–c* part cut through, *d–e* surface on which the flap, *f*, rests, opening inwards only; *g*, wall of bladder set with absorbing hairs within and glandular hairs without; *k*, the stalk (secondary petiole). Magnified 20 diam.—After Cohn.

FIG. 385.—Two leaves of sun-dew (*Drosera rotundifolia*). *A*, in expanded position showing the tentacles. *B*, shortly after the capture of an insect. The tentacles on the right half are inflexed to bring the glandular tips in contact with the prey. Magnified 2½ diam.—After Kerner.

faces are also merely protective against the visits of unwelcome guests, who steal nectar or pollen. (See ¶ 488.)

469. 3. **By movements of traps and adhesive surfaces.**—Somewhat more complex methods of capture are exhibited by leaves which have special movements connected with traps or sticky surfaces. The sundew of our swamps has the edges and surface of the leaves covered with many outgrowths,

FIG. 386.—Cluster of leaves at the base of flower stalk of Venus' fly-trap (*Dionæa muscipula*). One-half natural size.—After Drude.

each of which is tipped by a large gland (fig. 385). The clear, glistening fluid, a large drop of which is secreted by each gland, is sticky enough to entangle even insects of considerable size, which alight upon the leaves. The viscid secretion envelops the struggling insect, and at the same time the branches of the leaves bend slowly inward until more and more of the sticky glands are thrust upon it. The character of the secretion then changes. It becomes more watery and contains ferments which soon digest the softer parts of the

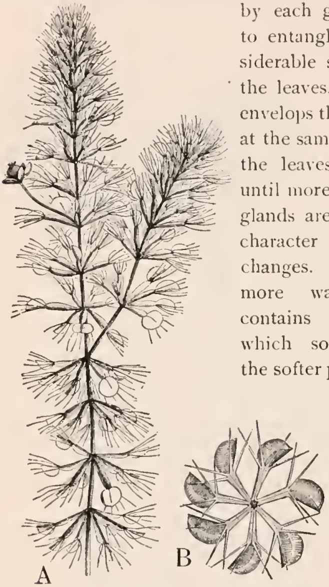


FIG. 387.

FIG 388.

FIG. 387.—*A*, blooming plant of *Aldrovandia vesiculosa*. Natural size.—After Drude. *B*, a single circle of leaves seen from the center above, showing stalk and two semicircular lobes. Magnified 1½ diam.—After Caspary.

FIG. 388.—Transverse section through closed trap of *Aldrovandia*, showing on inner face long sensitive hairs and many absorption hairs. Only the central part is three layers of cells thick; a broad margin is only one cell thick. Compare appearance in *B*, fig. 387. Magnified 20 diam.—After Caspary.

body. These are absorbed, and play an important part in the nutrition of the plant.

Dionæa (fig. 386) and its water mate, *Aldrovandia* (fig. 387), have leaves whose blades are somewhat like a spring

trap. The blade is two-lobed, with a hinge along the middle (figs. 205, 388). The hinge is in reality a cushion of tissue upon the back, which quickly throws the two halves of the leaf together when the sensitive hairs on the inner face of the trap are touched. The movement is sudden enough in *Dionæa* to catch the slow-flying insect, or, in *Aldrovandia*, the minute water animal. The prey is prevented from escaping by the interlocking, tooth-like lobes along the edges of the leaf. Digestion and absorption of the nitrogenous materials follow.*

II. Herbivorous animals.

470. Protection.—While a really insignificant number of minute animals are eaten by plants, a very large number of plants find it necessary to protect themselves in some way against destruction by browsing animals, insects, snails, and slugs. Since the animal world relies for its food supply ultimately upon the green plants, it is plain that no such protective measures are completely effective. The protection, therefore, may be looked upon as a protection against extermination rather than against injury. As protective adaptations against browsing animals are usually reckoned:

471. 1. **Armor**, in the form of hard, leathery, sharp-edged, woolly, bristly, or sticky parts, especially leaves (figs. 361, 362, 364, 389); or thorns (figs. 157, 390), prickles (fig. 115), or stinging hairs (fig. 391).

* Travesties upon these strange methods of nutrition appear periodically in newspapers, and plants of remarkable size and forbidding aspect are represented as capturing birds, animals, and even men, that venture into their neighborhood. It should be noted, therefore, that in all cases the plants which capture animal food entrap only the smaller animals, scarcely any of them, except those caught by the pitcher plants, larger than the common house-fly.

472. 2. **Distasteful or injurious substances**, such as volatile oils, camphors, acids, tannins, alkaloids, etc. The milky juice of plants like milkweeds, which often contain acrid substances, may also be protective.

473. 3. **Mimicry.**—Certain plants which are not distasteful or disagreeable have adopted the same form of leaves and stem and the general habit of those which grazing animals have found distasteful. This mimicry causes them to be avoided, as well as the really hurtful ones which they imitate.

FIG. 389.

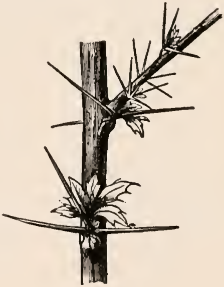


FIG. 390.

FIG. 391.

FIG. 389.—Edge of a leaf of a sedge (*Carex stricta*), showing alternate epidermal cells pointed and underlaid by two layers of mechanical cells. Magnified 200 diam.—After Kerner.

FIG. 390.—Part of a shoot of barberry in spring showing leaves of preceding year as persistent three-pointed thorns, in whose axils the buds are developing into the season's shoots. Natural size.—After Kerner.

FIG. 391.—A stinging hair of the nettle (*Urtica*), in longitudinal section. *x*, emergence in which the single-celled hair *abc* is sunk below *ab*. The knoblike apex *c* is easily broken off because the cell wall just below it is thin and brittle. The oblique cutting edge left pierces the skin like a hypodermic needle and some of the acrid cell contents enters the wound, causing intense itching. Magnified 60 diam.—After Frank.

474. 4. **Ants.**—In the tropics particularly, certain plants

secure themselves from the attacks both of browsing animals and leaf-cutting insects by encouraging the presence of colonies of warlike ants upon them and making provision for their defenders' wants. A very large number of species * protect themselves in this way. For the ants the plants provide (*a*) *nectar*,

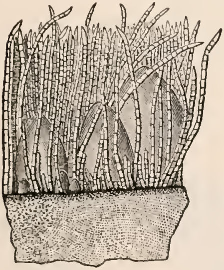


FIG. 392.

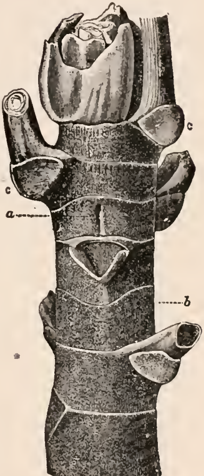


FIG. 393.

FIG. 392.—Bit of a section through the cushion (*c*, fig. 393) at base of leaf of *Cecropia*, showing the velvety hairs with which it is covered, and among them the egg-like bodies, rich in proteids and fats, which the ants collect and carry into their nests in the interior of the stem. Magnified about 10 diam.—After Schimper.

FIG. 393.—Apex of the hollow stem of a young *Cecropia*. *a*, the thin spot above a leaf, which at *b* has been gnawed through by the ants to make their nest in the cavity of the stem; *c*, the cushion at base of leaf stalk where food bodies grow. See fig. 392. Two-thirds natural size.—After Schimper.

similar to that secreted in the flower, i.e., a watery solution of various sugars, but secreted by nectaries outside the flower; (*b*) *fodder*, in the form of hairs (fig. 392), often of peculiar form, richly supplied with nutritive substances,

* More than three thousand are listed by Delpino.

growing from special parts of the surface, which are regularly eaten by the ants and grow again, so that a constant supply is at hand; (*c*) *dwellings* of various sorts. Certain plants have the stems hollow throughout, with special modification of the structure at certain spots, so that an entrance to these hollows may be readily made (fig. 393). In others, portions of the internodes are much enlarged and hollow; sometimes only the internodes in the region of the flower clusters are thus transformed. In other plants chambers are produced by the bladdery enlargement of the under part of the leaf near the midrib (fig. 394). In some acacias the stipules are developed as massive thorns, which the ants inhabit.

475. Domatia.—Somewhat similar dwelling places, though less perfect, are provided by many plants for the mites. These dwelling places are in the form of minute shelters usually upon the under side of the leaves. They are generally formed by hairs roofing over an angle of the veins, or by various outgrowths, folds and pits (fig. 395). Their significance is not at all clear.

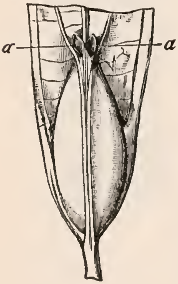


FIG. 394.

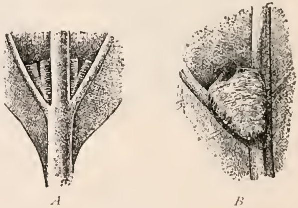


FIG. 395.

FIG. 394.—Under side of the base of the leaf blade of *Tococa lancifolia*, showing bladder on each side of midrib, each with entrance at *a*, *a*. Natural size. (?)—After Schumann.

FIG. 395.—Domatia on under side of leaves. *A*, between midrib and laterals of *Psychotria*. *B*, between midrib and lateral of the linden (*Tilia Europæa*). Magnified about 5 diam.—After Lundström.

476. 5. **Crystals.**—Plants protect themselves against soft-bodied animals, such as snails and slugs, by means of the sharp-pointed crystals which are present in the leaves of many species. According to Stahl, all tissues containing these crystals are avoided by such animals, but will be readily eaten by them after the crystals are removed.

II. REPRODUCTIVE ADAPTATIONS.

CHAPTER XXVI.

PROTECTION AND DISTRIBUTION OF SPORES AND SEEDS.

THE present knowledge of reproductive adaptations among the flowerless plants is very imperfect, though probably many exist. This chapter must, therefore, discuss chiefly the adaptations in the more complicated reproductive structures of seed plants which have been most studied, with only incidental allusions to such arrangements in the lower plants.

I. Protection against bad weather.

477. By movements.—Spores unfitted to resist low temperatures or wetting must be protected from rain, cold, and similar conditions. When nectar is secreted in the flower as an attraction to insects it is liable to be washed out by rain unless access of water to the interior of the flower is prevented. To avoid these dangers, many plants upon the approach of unfavorable weather bend their leaves so as to close the flower (fig. 396), or arch the stalk so as to turn the blossom into such a position that the rain or snow will not reach the sporangia or the nectaries. These movements of the leaves and stalk are combined in various ways to meet the needs of each particular form. All of them are growth

movements, brought about by variations in light and temperature, which act as stimuli. (See ¶ 286.)

II. Adaptation to distribution of spores.

The fact that spores are found in every group of plants from the lowest to the highest makes it probable that a great

FIG. 396. FIG. 397.

FIG. 396.—*A*, flower of California poppy (*Eschscholtzia*), opened in sunshine; *B*, the same, closed in wet weather. Natural size.—After Kerner.

FIG. 397.—*A*, aerial hypha of *Pilobolus crystallinus*, with sporangium. The hypha is swollen beneath the sporangium and very turgid. *B*, the same with sporangium torn off at base and being shot away by the violent escape of the mucilaginous contents of the hypha. Magnified about 10 diam.—After Kerner.

variety of ways will have been adopted by plants to secure their distribution. The more important ways may be grouped as follows:

478. 1. **By turgor and tension.**—Among the fungi, spores are often projected from the spore case by the pressure upon

it of neighboring cells, increasing until the sporangium ruptures suddenly and the spores are shot out like projectiles. In some cases the whole sporangium is thrown off in this fashion, often to the distance of a meter or more (fig. 397).

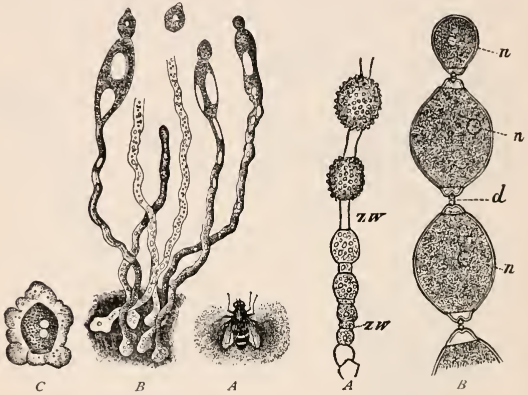


FIG. 398. FIG. 399.

FIG. 398.—*A*, a fly killed by the fly fungus (*Empusa Muscæ*), stuck to wall by hyphæ and surrounded by a halo of the spores. Two-thirds natural size. *B*, hyphæ projecting into the air from the body of the fly, from whose tips spores are being shot off. Several are shown in various stages of development. The turgor of the enlarged end of hypha finally ruptures the attachment of the spore and it is shot off surrounded by the mucilaginous contents which cause it to adhere to any object struck. Magnified 200 diam. *C*, a spore enveloped in mucilage. Magnified 420 diam.—After Kerner.

FIG. 399.—*A*, spore chain from a fructification (*æcidium*) of the cranberry rust (*Calyptrospora*). *s*, *s*, mature warty spores separated by an intermediate cell, *zw*, which has arisen by the division of the spore fundament by a transverse wall into a large upper and a small lower cell. The upper becomes the spore and the lower the intermediate cell which elongates, loses its contents, and dies; its wall becomes mucilaginous and so loosens the spores. Magnified 420 diam.—After Hartig. *B*, three spores at tip of an acropetal chain; the terminal spore therefore smallest. A disjunctor, *d*, has been formed between the layers of the partition wall and has forced them apart. The white area between two lowest shows area formerly connected. *n*, nucleus. Magnified 520 diam.—After Woronin.

The fungus which attacks and kills house flies in summer casts off the single spore from the end of the stalk carrying it by the bursting of the end of this stalk through excessive turgor (fig. 398). With the spore goes the contents of the

stalk, so that it is surrounded by a mass of mucilage, thus enabling it to adhere to any object which it strikes.

Filaments carrying the spores often twist upon drying and thus jerk off the spores as they suddenly slip past some obstruction. When spores are produced in chains, either the walls of a special cell or a layer of the cell-wall between them may act as a separator by its alteration into mucilage (*A*, fig. 399). In some cases the spores are wedged apart by the secretion, between the layers of the wall joining them, of a cellulose plug which gradually elongates into a slender spindle to whose tips the spores are so slightly attached that the lightest breath carries them away (*B*, fig. 399). The elaters of the liverworts (fig. 11 and ¶ 321) serve in some cases to sling out the spores when the capsule bursts; in other cases, as in *Marchantia*, they entangle the spores, insuring gradual and preventing too sparing distribution. The teeth around the mouth of the capsule of mosses serve to distribute the spores at opportune intervals, instead of having them emptied out all at once. In some mosses the teeth are erect or recurved when dry, but upon being moistened they arch over the mouth, thus forming a nearly closed cover (fig. 400). Others have the teeth arched over the mouth when dry or permanently fastened together by their tips, thus narrowing the opening and allowing the spores to sift out between them. In some cases the teeth, by their form and hygroscopic curvatures, serve to sling out the spores to a short distance. In many ferns the annulus of the spo-

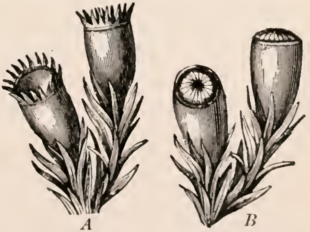


FIG. 400. Capsules of a moss (*Grimmia*) after fall of lid. *A*, teeth erect when dry, leaving capsule widely open; *B*, the same in damp weather. Magnified about 10 diam.—After Kerner.

rangium tends to straighten itself upon drying, thus rupturing the sporangium. After bending backward for some distance until the tear gapes wide, it suddenly straightens and hurls the spores to a considerable distance (fig. 401).

FIG. 401.—Sporangia of the male fern (*Aspidium Filix-mas*) scattering the spores. *A*, closed; *B*, burst by the drying of the annulus; *C*, the annulus after becoming strongly recurved is just returning to a nearly straight form and the spores are thereby being hurled toward *B*. Magnified about 65 diam.—After Kerner.

479. 2. **By water.**—In perfectly quiet water, distribution of spores depends solely upon their own motor organs. Only zoospores (see ¶ 306) are so furnished. For these a film of water is sufficient, and they may swim some distance over what appear to be merely moist surfaces. Most of the algæ and fungi living in water form zoospores. Their production is often controlled by external conditions, the formation of new individuals being thus provided for when the old are threatened with destruction.

In flowing water and by currents, non-motile spores are readily distributed. Even such relatively heavy spores as the resting spores of algæ may be carried long distances by water currents. The microspores (pollen) of aquatic seed plants are sometimes carried to the stigma by water currents, as in *Vallisneria* (fig. 402).

480. 3. **By air currents.**—Spores may be readily carried by the air on account of their small size and their ability to

withstand dryness. Most spores float in the air for some time like dust particles, and the slightest current is adequate to lift many and carry them along. Spores of most non-aquatic

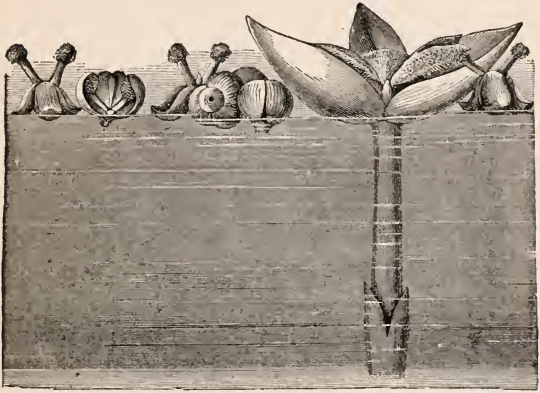


FIG. 402.—Pollination of eel-grass (*Vallisneria spiralis*). The large flower is a pistillate one, with stigmas fringed on under side. About it are floating staminate flowers in various stages of development, having broken from submersed stems which bore them. The ones on the right and left have the boat-shaped perianth lobes turned back, stamens mature, and pollen exposed; one has floated so that the pollen is brought into contact with the stigma of the pistillate flower. Magnified 10 diam.—After Kerner.

fungi, mosses, and fernworts are distributed by air currents. The microspores of some seed plants, especially the common forest trees, are carried in this way.

481. 4. **By animals, especially insects.**—It is the seed plants, particularly, which have adapted themselves to the distribution of spores by this means. The development of the male plants in this group must be completed in the neighborhood of the female plants, for the reason explained in ¶ 386. The microspores must, therefore, be carried to the ovules of gymnosperms or to the stigmas of angiosperms

and lodged there. It has been clearly shown not only that adaptations for securing this result have been developed, but also that there have arisen various ingenious adaptations to secure cross-pollination and to prevent close-pollination. (See ¶ 358.) Some of these may be here enumerated.

482. Adaptations for cross-pollination.—(*a*) The separation of the stamens and pistils, staminate flowers and pistillate flowers being produced upon the same plant or even upon different plants of the same species; (*b*) the early ripening of the stamens so that they discharge their spores before the stigma of the same flower is exposed or receptive, or *vice versa;* (*c*) arrangements preventing the pollen from reaching the stigma of the same flower, which vary according to the different modes by which the transfer of the pollen is made; (*d*) the failure of fertilization to occur when close-pollination happens. In such cases the pollen is said to be impotent. This means that the male plants are either not completely formed by it, or that their sperms do not stimulate the egg to development.

483. Adaptations for close-pollination.—But close-pollination, even though it results in weaker offspring, is better than entire failure to produce progeny. Therefore, some plants permit close-pollination in the event of failure to secure cross-pollination, while a few have adaptations which insure it. Our common violets produce in the late spring and early summer inconspicuous blossoms which do not open, containing stamens with few pollen grains. These flowers, however, produce seed abundantly, and always by close-pollination. Various other species have similar arrangements.

484. Adaptations to insects.—The adaptations to secure cross pollination through the visits of insects are so numerou and so varied, and the advantage in the number and weight of seeds produced is so marked, that for most seed plants

cross-pollination must be considered the far more desirable process. Flowers are adapted to insect visitors in the following ways:

485. (*a*) **Food.**—They provide for their visitors edible substances, such as nectar and pollen,* material for nest building, shelters, or breeding places.

486. (*b*) **Advertisements.**—They advertise the presence of such attractions in two ways, which are sometimes combined, and insects accustomed to visit flowers quickly learn to know what the advertisements mean. (i) *By color.* Flowers are so colored as to attract notice; and this is further secured by the large size of individual flowers or by massing many small flowers into close clusters. (ii) *By odor.* Odors are due to volatile oils, usually in the epidermis of the petals or sepals, often curiously localized. Dusk- and night-blooming plants often have heavy odors.

487. (*c*) **Form and position of parts.**—Many plants by the form of their flower leaves provide landing places for welcome visitors. Guides to the location of the nectar, in the form of grooves, folds, hairs, lines of color, etc., are often present. The form and position of the stamens and pistils is often such as to insure the desired transfer of pollen. These positions may be permanent or they may be secured by movements at opportune times. Among the movements are those due to turgor and those due to the presence of motor organs. In a very large number of cases, by the form of the flower-leaves and the essential organs the plant is adapted to visitation by particular insects, and if these are not present, or if their access is denied, constant failure to set seeds is the result. Thus one may distinguish plants adapted to bees, moths, butterflies, flies, birds, or even snails.

488. (*d*) **Exclusion of unwelcome visitors.**—In addition to

* The microspores are often produced in great excess of the plant's own needs.

provision for welcome guests must be enumerated the methods of excluding unwelcome guests, which on account of their size and habits are unable to bring about the desired transfer of the pollen, while at the same time they rob the plant of nectar or pollen provided for more acceptable visitors.

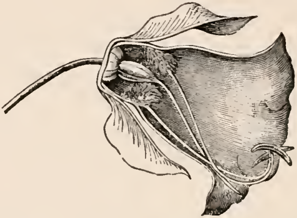


FIG. 403.—Flower of *Cobæa scandens*, halved; showing tufts of hairs on the base of the filaments, of which there are five; these close the bottom of the corolla cup where nectar is secreted against intruders. Three-fifths natural size.—After Kerner.

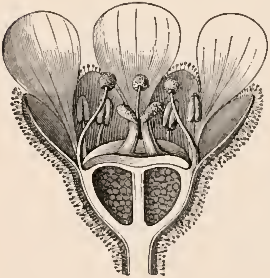


FIG. 404.—Flower of a saxifrage (*Saxifraga controversa*), protected against invasion by the numerous sticky glandular hairs on the flower stalk, ovulary, and calyx. Magnified several diam.—After Kerner.

(i) Various *obstructions within the flower* may render access to the nectar impossible to the smaller and weaker insects, while allowing others to reach it. Such obstructions are formed by folds, hairs, and other outgrowths upon the flower leaves or the essential organs (fig. 403). (ii) *Obstructions outside the flower* may exclude crawling insects. Such are sticky surfaces and hairs (fig. 404), moats about the stem formed by cup-shaped leaves holding water, or those formed by water in which swamp plants grow. (iii) The *time of bloom-*

ing also prevents the visits of any insects except those flying at that particular season.

III. Adaptations to the distribution of seeds.

489. After the ripening of the seed various devices and forces operate to scatter them at as great a distance as possible from the parent, so that the young plants will not come into competition with the old ones or with each other. This object, which is secured in lower plants by the distribution of the spores, can only be attained in seed plants by scattering the seed, because the megaspore is not set free; the ga-

A

FIG. 405.—Elastic valves for slinging seeds. *A*, fruit of wild geranium (*G. palustre*) with persistent calyx. The five carpels surround an elongated torus, from which they break first at bottom; curling upward suddenly they sling the seed out of the basal part which has cracked along the inner side. *B*, fruit of touch-me-not (*Impatiens noli-me tangere*), one sound, the other bursted. The carpels have curled up elastically from the base and slung out the seeds. Natural size. After Kerner.

metophyte is consequently developed within the sporophyte; and the embryo sporophyte is likewise enclosed by the old sporophyte (See ¶ 408.)

The methods by which distribution is secured may be grouped as follows:

490. 1. **Distribution by tension and turgor.**—Some plants (e.g., witch hazel) as they ripen the pericarp, alter its tissues in such a way that the contained seeds are compressed when the pericarp dries, and after it opens they are pinched out from the narrowing valves, as a wet apple or melon seed may be shot from between the thumb and finger. In others (e.g., touch-me-not and cranesbill) the parts of the pericarp shorten on one side until the strain breaks them loose, when they become suddenly elastically curled and sling the seeds contained to a considerable distance (fig. 405). Somewhat similar causes, i.e., curvatures due to unequal shrinkage or swelling of the tissues, enable some fruits with long awn or bristles to creep over the ground or to bury themselves in it when alternately moistened and dried (fig. 406). The pericarp of the squirting cucumber is so distended by the almost liquid pulp surrounding the seeds that it ejects the mass through the opening formed by its separation from the axis.

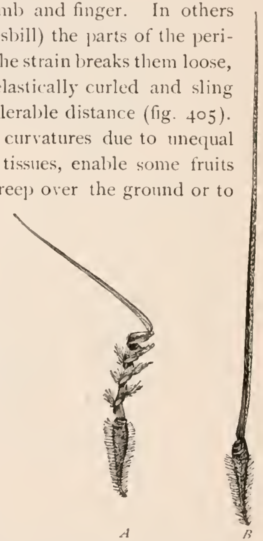


Fig. 406.—Pieces into which the fruit of storksbill breaks. There are five of these each corresponding to a carpel and arranged on the sides of a prolonged torus as in *A*, fig. 405. *A*, when dry the beak is spirally coiled; *B*, when moist. The base is hard and very sharp. Magnified about 2 diam.—After Noll.

491. 2. **Distribution by water.**—In some plants this is secured by the fact that the fruits open only when moistened. In such cases the seeds may be either washed out from the opening pods by rain, or may be loosened in many other ways. The seeds are thus set free at the time best suited to their prompt germi-

nation. Some plants, adapted to distribution by water, are provided with floats. These floats may consist either of the enlarged and bladdery pericarp (or some portion of it), or of the spongy, air-filled seed coat. The fruits or seeds are thus made more buoyant and float upon the surface instead of sinking as usual. Naturally, water-loving plants are chiefly adapted to distribution in this manner.

492. 3. **Distribution by winds.**—Some plants which secure their distribution by winds are only lightly attached to the soil at maturity, so that they are readily uprooted and carried bodily, when dry, for considerable distances by the wind. The transfer is facilitated by the incurving of the branches upon drying, so that the uprooted plant is more or less spherical in outline, or by the fact that the plant is normally spherical by the proportion of the branches. Such plants are known as "tumble weeds." Singly or aggregated in large bundles they are rolled over plains and prairies for long distances, shaking out their seeds as they go, or opening their fruits when moistened. Another adaptation for distribution by the wind is the small size of some seeds. Those of some orchids are so diminutive that it takes 500,000 to weigh 1 gram.

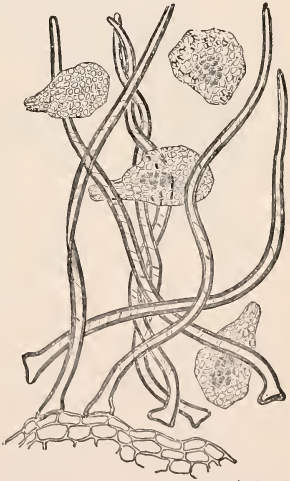


FIG. 407.—Seeds of an orchid (*Vanda teres*), with cells of seed coat bladdery and filled with air. These seeds are ejected from the capsule by the contortions of the hairs on its inner faces which curve and twist as the moisture in the air varies. Magnified 100 diam.—After Kerner.

Such minute seeds are readily blown long distances by the wind. Relative lightness is also secured by the construction of some seeds, which are surrounded by a voluminous coat containing many large air spaces (fig. 407). Outgrowths from parts of the seed coat or pericarp also secure the same end. In such cases the fall of the fruit or seed though the air is so retarded that it may be carried laterally some distance by the wind. No seeds, however small, float long in quiet air, since buoyancy is derived only from air-

FIG. 408.—Fruits with wings. *A*, fruits of ailanthus tree (*A. glandulosus*), each carpel with double wing. *B*, fruits of a maple tree, each carpel with a single wing. Natural size.—After Kerner.

containing tissues. A flattened form of the fruit or seed is very common, and this form is often exaggerated by the formation of wings, i.e., of thin outgrowths from the surface (fig. 408). The center of gravity in such cases is so placed that the plane of flattening will be nearly horizontal when the seed falls. These fruits or seeds sink from 1 to 30 times as slowly as the same bodies without the wing. Sometimes specialized persistent flower leaves, either corolla or calyx, are used for this purpose, as in dandelion and thistle (fig. 409).

Hairs of the most various origin are produced in such numbers and position as to form either parachutes or tangled woolly envelopes to the fruit or seeds (figs. 410, 411).

FIG. 410.

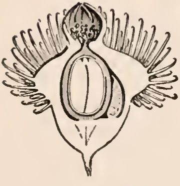
FIG. 409.

FIG. 409.—Heads of fruits of the dandelion; single fruits falling, exposing common torus and involucre. Natural size.—After Kerner.

FIG. 410.—Fruits of a willow, burst, and allowing the seeds, each with a tuft of silky hairs (coma), to escape. Natural size.—After Kerner.

493. 4. **Distribution by animals.**—To secure this there are two general methods observable. (*a*) The seed or fruit is either adapted for transport by adhering to the body of the animal; or (*b*) the seeds are surrounded by edible parts, and at the same time so protected against the digestive juices that they may pass uninjured through the alimentary canal. A few plants are distributed by animals which collect and hide their fruits or seeds (e.g., the squirrels). The adhesion of fruits or seeds to animals, especially to those which are provided with

Fig. 411.—A fruit of Barbadoes cotton, open, exposing the voluminous hairs (commercial cotton) which clothe the seeds. Natural size.—After Kerner.



A B

Fig. 412. Fig. 413.

Fig. 412.—Fruit of *Agrimonia*, halved; showing torus, carrying calyx and withered stamens above, covered with hooks, and enclosing the hard pericarp, with a single seed. A pistil which did not mature lies to the right. Compare torus in fig. 288. Magnified about 8 diam.—After Baillon.

Fig. 413.—Fruit of tick trefoil (*Desmodium Canadense*). *A*, pods which separate into sections, each containing one seed. They are covered with stiff hooked hairs, some of which are shown enlarged at *B*. *A*, natural size. *B*, magnified about 20 diam.—After Kerner.

fur, is generally secured either by surfaces made adhesive by the sticky secretion from glandular hairs, or by the development of outgrowths in the form of hooks or barbed prickles (figs 412, 413, 414, 415). A few water animals and wading birds distribute seeds which happen to fall into the mud by the adhesion of this mud to their bodies.

The fleshy fruits with edible parts are usually colored to attract the notice of the fruit-eating animals. Seeds which escape crushing by the teeth or grinding in the gizzard are apt to be in condition to germinate when voided. The seeds of the mistletoe are separated from the pulp of the berry by the birds which eat them, and, sticking to the bill, are wiped off on the branches of trees, where they germinate.

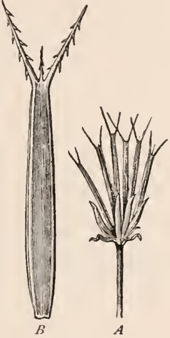


FIG. 414.

FIG. 415.

FIG. 414.—*A*, cluster of fruits of Spanish needles (*Bidens bipinnata*). *B*, a single fruit enlarged, showing barbed awns, representing the calyx lobes, by which it adheres to animals. *A*, natural size; *B*, magnified 2½ diam.—After Kerner.

FIG. 415.—Fruit of cockle-bur (*Xanthium strumarium*), halved, showing two seeds, the upper of which usually germinates a year later than the lower. Natural size.—After Arthur.

The adaptation of plants to any one of these agents of distribution is likely to be more or less effective with other agents. For example, the tufts of hairs which increase the buoyancy of the seed in air would be equally effective should the seed chance to alight upon water, or they may suffice to entangle the seed in the fur of animals.

494. Adaptations for germination.—Adaptations for distribution not infrequently also secure advantage in germination. It is important for many seeds that they be anchored to the ground when they have once been transported, so that

they may not be subject to further disturbance. Such anchorage is sometimes secured by the transformation of the outer layer of cells into mucilage, so that the seed, upon becoming wet, is stuck fast to the soil ; or by the tufts of hair which, once wetted, cling to the surface of the earth ; or by barbed bristles and hygroscopic awns which, having become entangled among the grass, work a pointed seed body deeper by every change of moisture (fig. 406).

Study of plants in relation to their surroundings, therefore, yields the conclusion that these organisms are wonderfully plastic, responding either temporarily or permanently to every change in conditions. It is greatly to be desired that the too common thought of plants as only *things to be classified* may be replaced by the conception of them as *beings at work, to be studied alive.*

APPENDIX I.

DIRECTIONS FOR LABORATORY STUDY.

Part I: Morphology.

I. ALGÆ.

A. PLEUROCOCCUS

1. Examine with a lens pieces of bark bearing *Pleurococcus* and similar algæ. Note the irregular distribution of the green granular heaps of plants. Is there any similarity to the distribution of higher plants over uncultivated areas?

2. After soaking a piece of bark for a few minutes, scrape off with the nail or a dull knife blade some of the green material, spread it as well as possible in a drop of water on a slip of glass, cover it with a piece of thin glass, avoiding air-bubbles, and examine with a lens. Observe the minuteness of some of the specks, which are mostly single plants. The larger ones are clusters of plants.

3. *Demonstration.* Examine slide under a high power and observe the form and color of single plants. Notice many consisting of two or more cells still joined together, resulting from cell division. (¶ 19, fig. 18.)

B. NOSTOC or RIVULARIA.

1. Observe the size and form of the colonies, and the consistence of the jelly enclosing them. (¶ 13.)

2. Crush a bit of a *Nostoc* colony or a whole one of *Rivularia* between two glass slips, remove the upper slip, cover with water and observe the coiled (Nostoc) or radiating straight filaments (Rivularia) embedded in the jelly. (Figs. 13, 14.)

C. OSCILLARIA.

1. Observe the color of a bit of *Oscillaria;* contrast it with that of *Pleurococcus.* (¶ 11.)

2. With needles tease out the specimen in a drop of water on a glass slip; observe the delicate thread-like form. (Fig. 15.)

3. Transfer a bit of living *Oscillaria* to a small glass dish or white individual butter plate with a little water; protect it from drying up with a cover; 24 hours later observe the position of the filaments. (¶ 14.)

4. *Demonstration.* Dip a considerable mass of *Oscillaria* in hot water for a moment and put in a white butter plate with as small a quantity of water as will cover it. As the water evaporates observe the color deposited on the dish at the edge of the water. (¶ 11.)

D. SPIROGYRA.

If fresh material is available examine a few filaments in a white dish for color. If preserved material is used, stain red by immersing for a few minutes in eosin (cheap red ink will answer).

Examine with a lens. Observe:

1. Length; whether broken or whole; whether with or without branches.

2. The delicate partitions, like white lines, crossing the green (or red) filaments, dividing the protoplasm of one cell from another. Can the form of the chloroplasts be seen? (Cf. fig. 24.) This can be readily seen only in the larger species. (¶ 25.)

3. *Demonstration.* Mount a few fresh filaments in water. Show under moderate power the form of the chloroplasts; the reserve food nodules; the nucleus. (Fig. 24.)

4. Examine conjugating specimens with a lens after staining. Observe the *conjugating tubes* connecting two filaments like rungs of a ladder (¶ 361); the *zygotes* or zygospores (¶ 365) as blackish dots in some cells. Are they in one filament only or in both?

5. *Demonstration.* Mount conjugating filaments and show the conjugating tubes and zygospores. (¶ 375, fig. 303.)

E. CLADOPHORA.

If fresh material is at hand observe in a white dish; if preserved specimens are used stain for a few minutes in eosin.

1. How is the plant attached?

2. Observe form and particularly the abundant branching. Can a single main axis be traced? How many branches arise at one point? (Fig. 29.)

3. *Demonstration.* Kill and fix the protoplasm of some filaments of *Cladophora* by placing them in chrom-acetic acid (water, 990 parts; chromic acid, 7 parts; acetic acid, 3 parts) for 1 hour; wash out the acid by placing them in running water for several hours (6–24) or in a large dish of water changed several times in the course of 24 hours; stain by placing them in alcoholic borax-carmine or hæmatoxylin for several hours. Mount in water. Examine with high power of microscope. Each segment of the filament will be seen to contain several nuclei (more deeply stained than the body protoplasm and the numerous chloroplasts), showing the segments to be *cœnocytes* and not true cells. (¶ 28.)

F. STONEWORT (*Chara* sp.).

Place the plant in a glass dish with clean water. Set it over a black background if preserved (and therefore colorless) material is used. If fresh, a white dish furnishes a good background.

1. From the base of the axis carefully remove the mud by washing. Observe the colorless rhizoids. (¶ 37.)

2. In the body of the plant observe (*a*) the central axis; (*b*) the whorls of lateral dwarf branches ("leaves") at intervals ("nodes"); (*c*) the single lateral axes arising among the whorled dwarf branches. (¶ 33, fig. 35.)

3. Trace the main axis to its tip. Compare the distance between whorls toward the tip. How do they stand close to tip? Dissect away the outer ones successively. What is within?

4. *Demonstration.* Prepare or obtain a longitudinal section of the apex of the axis, and show under compound microscope the apical cell and the differentiation and growth of its successive segments. (¶ 39, fig. 38.)

5. Compare the length of the various lateral axes. Compare the tip of any of the long lateral axes with that of the main axis. What do the observations show as to the duration of growth of these?

6. Compare the length of old and young dwarf branches. Compare their tips with those of either lateral or main axes. What do these observations show as to the duration of growth of the dwarf branches? Observe the form and distribution of the branchlets. Can they continue to grow in length?

7. Hold a bit of the main axis (use decalcified plants) between the halves of a piece of pith and with a very sharp knife or a razor cut a transverse section of the axis. Mount on a slide in water with cover glass, and examine with lens. Observe the central cell, surrounded by a row of cortical cells. (Fig. 37.)

8. Trace the course of the rows of cortical cells by examining the surface of the axis with lens. Note the short projecting cells which roughen the surface. (¶ 35.)

9. *Demonstration.* If fresh material is available mount a living rhizoid in water and show the rotation of the lumpy protoplasm.

10. On the lower whorled branches observe the black ovoid *resting spores*, surrounded by a paler cortex, with a crown of five cells at the free end. Study these on successively higher and higher branches, and observe differences in color, and finally of shape. What is the form of the youngest (*ovary*)? (¶ 389, fig. 313.)

11. Examine at the same time the spherical *spermaries* (orange or scarlet in fresh specimens) which are found with some ovaries. Why are they absent on older branches? Can any trace of them be found? (¶ 383, fig. 313.)

12. *Demonstration.* Mount young ovaries and show the central cylindric *egg*; the five cortical cells, straight in the youngest, spirally twisted in older ones, terminated by five crown cells, between which the sperms make their way to the egg.

Mount entire spermary; also on another slide one teased out with needles; show the eight *wall cells*, united by zigzag edges, each carrying a *handle-cell* on its inner face, from which arise numerous filaments composed of disk-like cells each containing one *sperm*.

G. POLYSIPHONIA (*P. variegata*).

Place a plant in a glass dish over a black or white background. Observe

1. The form of the body and the mode of branching. (Fig. 39.)

2. The mode of attachment at the base, if specimens are entire.

3. *Demonstration.* Mount the tip of one of the branches and show the high, dome-shaped *apical cell*, with segments cut off successively from its base, to be later themselves divided longitudinally. (¶ 39, fig. 41.)

4. Cut a transverse section of a medium sized axis and observe the four large peripheral cells, surrounding a central cell; the latter to be seen only under compound microscope. (¶ 38, fig. 40.)

5. On some plants observe that the smaller branches are swollen here and there with more opaque contents at these points. These are the *tetrasporangia*. Compare their size as they are traced tip-wards. What do you infer as to their origin? (¶ 317, fig. 229)

6. *Demonstration.* Mount tetrasporic branches and show the tetraspores.

The sexual reproduction is so specialized that beginners should not be perplexed with it. (See p. 288.)

H. BLADDER WRACK (*Fucus vesiculosus*).

Place plant in a glass dish or a pan of water. Observe

1. The general form of the body or thallus; its mode of branching. (¶ 41.)

2. The thicker central region forming a *midrib*, with thinner wings. (Figs. 42, 43.)

3. Downwards, the thickening of rib and death of wings to form *stalk* near base.

4. The lobed *attachment disk* at base of stalk.

5. The swollen regions of the wings here and there. Cut into one of these and observe that it is a *bladder*.

6. The notched tips of some branches; the enlarged and more or less distorted tips of most, forming the *receptacles*.

7. Scattered on the thallus minute elevations, from which protrude through an opening at the top a tuft of fine hairs. These are the mouths of the *hair pits*.

8. Crowded on the receptacles, larger warts with a hole at top and similar protruding hairs. These are the mouths of larger pits, *conceptacles*, which contain the sex-organs.

Cut two thin transverse sections of the thallus, one through the bladder and the other through the general thallus. The latter should include a hair pit. Examine them with a lens and observe

9. In the latter, the denser outer tissues; the cortical region; the looser inner ones, of elongated threads and much mucilage, the medullary region; the thicker denser midrib; the form of the hair pit.

10. Note the difference between the structure of the bladder and the unswollen wing. Which region is altered to form the bladder?

Cut thin transverse sections through the center of the recepta-

cles of male and female plants. If another species than *Fucus vesiculosus* is used (e.g., *F. platycarpus*) both sex-organs will be found in same conceptacle. If the sexes were not collected separately and marked they can only be recognized after cutting sections by the descriptions and figures given. Observe

11. The form and size of conceptacles. Compare with hair pit.

12. In male conceptacles, the crowded and tufted hairs, some of whose terminal cells are spermaries. (¶ 381, figs. 309, 310.)

13. In female conceptacles, the ovaries of various sizes. The larger ones are mature. (¶ 389, figs. 324, 326, 327.)

14. *Demonstration.* Mount very thin sections of male and female conceptacles or some of the teased out hairs from them and show:

The oval spermaries, filled with rounded sperms.

The ovaries, young and old; in the latter, the eight crowded and therefore angular eggs, which round off on escape.*

II. FUNGI.

A. BLACK MOLD (*Rhizopus nigricans*).

Before any white or black dots appear on the mold, examine the *vegetative hyphæ*. (¶ 48.) These are of two kinds, (*a*) those running over the surface of the bread; (*b*) those penetrating it.

1. Examine *a*. Lift up a few threads with a needle and mount them in water. Study with a lens. Are they white or colorless? Why then is the body composed of them (the *mycelium*, ¶ 50) white?

2. Examine *b*. With needles tease out hyphæ from a bit of bread in water; free them as far as possible from the débris and mount. Compare with *a*.

After mold has begun to show black dots (*sporangia*) examine.

3. Determine how the branches are placed which bear the sporangia. (Fig. 49.)

4. Compare the white (young) and black (mature) sporangia. Can you find the very smallest ones?

* If fresh material can be obtained demonstrate the sperms and eggs after escape from spermary and ovary. Expose a plant with mature receptacles which has been in sea water (or a 3 per cent. solution of sea salt) to the air for a few hours; mount in sea water on a slide some of the orange exudation which appears at the mouths of male conceptacles. The water will be found filled with spermaries from which are escaping motile sperms. The same treatment with female plants will demonstrate the eggs. By mixing drops of water containing sperms and eggs the process of fertilization may be watched.

5. Snip off a few ripe sporangia with scissors, handling them cautiously to avoid breaking or tangling them ; mount in alcohol * and examine. Crush (if not already broken) and observe numerous dust-like particles, the *spores*, which escape.

6. *Demonstration.* Mount a full grown but immature sporangium and show the structure of sporangium with septum grown up into it forming the columella ; the spores. (¶ 316, fig. 220.)

B. WHITE RUST (*Cystopus portulacæ*).

1. *Demonstration.* Boil a leaf of purslane for a minute or two in 5% potassic hydrate. Tease apart the tissues of leaf with needles on a slide, mount and show the *mycelium* of the fungus, consisting of tangled hyphæ ramifying among the cells of leaf. (¶ 51, 52.)

Examine a dried leaf. Observe

2. The white blisters (*spore beds*) here and there on the surface ; the thin membrane (the epidermis of the leaf) by which they are covered ; in older blisters the cracking and final disappearance of this skin. (¶ 312, fig 210.)

3. The white powdery *spores* which jar out or can be dislodged with needle.

4. *Demonstration.* Cut a transverse section through one of these spore beds and show the close set ends of hyphæ producing the spores in chains. (¶ 313.)

5. Cut a transverse section of the leaf or stem, mount and observe the numerous dark dots scattered through the tissues of the host. These are the resting spores with thick opaque walls.

6. *Demonstration.* Show in a similar section the spermaries and ovaries, and the various stages in the maturing of the fertilized egg into the resting spore.

C. MILDEW (*Microsphæra Friesii*, or *Erysiphe communis*).

Examine dried leaf bearing mildew. Observe

1. The whitish interlacing hyphæ on surface of leaf, forming the *mycelium*. (¶ 50.)

2. The distribution of the fungus ; does it cover the whole leaf or only occur in patches ? Compare the earlier and later gathered leaves as to this.

* Because water will not readily wet them. Replace alcohol as it evaporates ; it does so rapidly.

3. The pulverulent appearance on the younger leaves, due to *spores.*

4. *Demonstration.* Scrape a bit of the mycelium from the surface of the leaf after moistening it for a few minutes with a 5% solution of potassic hydrate. Mount and show (*a*) the colorless branching hyphæ ; (*b*) the erect branches bearing the spores ; (*c*) the spores.

7. Examine as before one of the older leaves. Observe the yellowish dots scattered over the mycelium, the immature *fruits.* (¶ 401, fig. 337.) Associated with these the black mature fruits. These contain sporangia with spores. (¶ 317, fig. 223.)

8. *Demonstration.* Mount and crush under cover glass some mature fruits ; show the sporangia (*asci*) and their contained spores. (Fig. 224.)

D. CUP-FUNGUS (*Peziza* sp.).

1. The mycelium penetrates the earth or rotting wood on which the fructification appears and cannot be dissected out. Only the *reproductive parts* (¶ 317) are to be examined. Observe the size, shape. and color of the cup. The red and orange cups usually lose their color in preserved specimens.

Cut a thin section from a piece of the cup at right angles to inner surface. Mount. Observe

2. The dense upper layer of parallel hyphæ (*hymenium*), with rows of black specks. The latter are the spores in the long parallel sporangia (*asci*). (¶ 317, fig. 222.)

3. The lower layer, less dense, of tangled hyphæ.

4. *Demonstration.* In a very thin vertical section show (*a*) the hymenium, with paraphyses, asci, and ascospores ; (*b*) the looser lower layers of interwoven hyphæ.

E. LICHEN (*Physcia stellaris*).

Soften the plants by soaking them in water for a few minutes. Observe

1. The mycelium, forming a connected leaf-like lobed thallus. Compare as many other forms as are available. (¶ 54*a*, fig. 225.)

2. Compare the color when dry and wet. In the latter condition, the mycelium is more translucent and the imprisoned green algæ show through more plainly. (Figs. 55, 377.)

3. The tufts of hyphæ extending from lower surface to bark, the holdfasts or *rhizines.*

4. Occupying the central region on the upper surface, the round colored disks, *apothecia*. Compare the form of the younger ones nearer the margin. What change occurs as they grow older? (¶ 317, fig. 225.)

5. Here and there, minute black specks, the mouths of sacs sunk in the thallus, called *spermogonia*.

Cut a vertical section through an apothecium and a part of the thallus on each side. Observe

6. The layers of the thallus; above and below, dense layers, the upper and lower *cortical layers*; between them, the *medullary layer*, with *green algæ* distributed unequally through it.

7. The form of the apothecium: its broad short stalk and rim; the convex surface of the disk. Is this more convex than before cutting? How shown? Why?

8. The layers of the apothecium; the upper (*hymenium*) of vertical parallel sporangia containing rows of black dots, the *spores*; the second (*sub-hymenium*) of fine, pale, tangled hyphæ; the third (*medullary layer*) with *green algæ;* the lower *cortical layer*. (Fig. 226)

9. *Demonstration.* In a very thin vertical section of apothecium show the sporangia (asci) and ascospores; the paraphyses.

10. Compare apothecium with the cup of *Peziza*. How are they different? Do these differences seem important? (Figs. 222, 226.)

F. MUSHROOM (*Agaricus* sp.).

1. The mycelium of this plant consists of rope- or ribbon-like strands of hyphæ ramifying extensively in the substratum. The *fructification* only is here studied (¶ 314). Examine this part fresh or in water. Observe in a mature one the two parts, *stalk* and *cap*. (Fig. 216.)

2. With a sharp long-bladed knife or razor cut the cap and stalk lengthwise through center. Is the stalk hollow throughout? Or is the central part only of different texture from outer? Determine differences of texture by teasing apart the hyphæ with needles.

3. Cut off stalk close under the cap. Turn the latter under side up. Observe the radial plates (*gills*) extending from margin to stalk. Do all reach the stalk?

4. Examine the young fructifications. By cutting them lengthwise observe the formation of the chamber from whose roof the

gills develop; the floor becomes thinner as the chamber enlarges, and finally ruptures, exposing the gills. Does any part of this floor (called the *veil*) adhere to the stalk or the edge of cap on mature fructifications?

5. If fresh mature fructifications are available cut away the stalk and place the cap on a piece of black paper,* gills down, resting on the stump of stalk, cover with a tumbler or bell jar, and examine after 24 hours the *spore print* formed by the great number of spores which have fallen from the surface of the gills.

6. *Demonstration.* Cut a very thin transverse section of a gill and show the hymenium covering the surface, with basidia carrying the free spores. (Fig. 213.)

7. Compare with mushroom various other fructifications of related fungi (*Hydnum*, *Boletus*, *Polyporus*, *Clavaria*). Observe the various forms by which extensive surface is secured for the hymenium. (¶ 314, figs. 215, 217, 218.)

III. BRYOPHYTES.

A. THALLOSE LIVERWORT (*Marchantia polymorpha*).

Examine an entire plant in water. Observe

1. The flattened horizontal body (*thallus*) with central line, the midrib, and thinner wings on each side.

2. The notched apex (the apical cell is at the base of this notch). (¶ 59.)

3. The mode of branching (*dichotomous*). Examine the tips and find one just branched. Do not confuse with notch of apex; when a tip branches there will soon appear two notches. Does the branch appear on the side of the older thallus, or are the branches equal at first? Are they equal when older? (¶ 58.)

4. The green lens-shaped bodies (*brood-buds*) growing at certain spots along the midrib, surrounded by an outgrowth which forms a cup-like rim about the cluster. Remove a brood-bud and observe its form, especially in full grown ones the two opposite notches, the growing points. (¶ 362, fig. 290.)

5. The air chambers (*areolæ*) of the upper part of the thallus, showing through the skin, best seen in older parts and with a lens. What is their form? Are they all alike? (¶ 57.)

* If the gills are light colored; if dark colored use white paper.

6. The openings into the air chambers, in the skin over each one.

7. Compare the under surface with the upper. Observe the numerous hairs. Discover the difference in place of origin and direction of growth of these. (¶ 56.)

8. Carefully pull off with forceps as many of these hairs as possible and notice the dark-colored overlapping outgrowths along the midrib, curving outward as they are followed forward, attached along their edges. These are the so called "leaves."

Cut a transverse section of the thallus through a brood-bud cup. Observe

9. The origin of the brood-buds (only the younger still remaining) over the midrib.

10. The difference between tissue of upper and under parts of thallus. (If fresh plants are available observe especially the difference in color.)

12. *Demonstration.* Cut a very thin transverse section of the thallus. Select a part passing through stoma and show

(1) The air-chamber; its roof, the skin, with chimney-like stoma in center; its sides a vertical plate of cells; its floor, with branched filaments of chlorophyll-bearing cells. (Fig. 58.)

(2) The large-celled colorless tissue forming the lower half of section; the sections of "leaves" arising near midrib and concave towards center.

The sexual branches are so peculiar and specialized that the beginner ought not to be puzzled with them.

B. LEAFY LIVERWORT (*Porella platyphylla*).

1. In what position do the plants grow with reference to the substratum?

Disentangle carefully a single plant.* Observe

2. The growing apex; the dying base; the distinctly dorsiventral habit. Enumerate the differences between the upper and under sides. (¶ 60.)

3. The mode of branching: a central axis, with lateral branches, themselves with lateral branches; i.e., *monopodial* and *bipinnate*. (¶ 65.)

4. The yellowish or brownish stem, covered with leaves unequally distributed.

* If dry, first soften by placing plants in hot water for a few minutes.

5. The two rows of large leaves on the upper flanks of the stem. How do they overlap? Turn the shoot over and note a third row of small underleaves in the center below; also right and left the lobes of the upper leaves. Determine the form of the under and upper leaves. Make an enlarged paper pattern of the latter showing how their ventral lobes are arranged. (Figs. 62, 63.)

6. *Demonstration.* Mount a leaf and point out the uniformity of cells and their abundant chloroplasts.

7. Examine male plants * and observe the male branches: short, abundant near the anterior end of main and lateral axes, with crowded, closely overlapping leaves, the anterior ones often pale.

8. Cut off a male branch; dissect leaves carefully and observe in the axil of each leaf a spherical yellowish body on a slender stalk, the *spermary.* (¶ 382, fig. 311, *B.*)

9. *Demonstration.* Mount a mature but unbroken spermary and show the single layer of cells forming a wall enclosing an opaque mass of *sperms.* If fresh, the spermary may rupture on being put into water and the sperms swim about rapidly in the field of the microscope.

10. Examine a female plant. On the under side observe very short lateral branches, bearing a pear-shaped tumid sac, the *perianth.* How is it constructed at the free end?

11. Examine old perianths; observe partly projecting from such the mature *sporophyte*, consisting of a brown spherical *capsule* on a pale slender stalk (*seta*). (The capsule is often bursted; if so, determine into how many pieces (*valves*) it splits.) To what is the stalk attached? (¶ 32, figs. 64, 65.)

12. Examine successively younger female branches (to be found toward the anterior end) and note various stages of development of the sporophyte. Find a young sporophyte, differentiated into stalk and capsule, but still enveloped by a thin membrane, formed by the enlarged body of ovary and surmounted by a brown bristle, the neck of the ovary. Determine what becomes of this membrane (*calyptra*).

13. *Demonstration.* Select the youngest female branch with well grown perianth, cut a median longitudinal section, or dissect away the perianth, mount, and show the group of several *ovaries*; some with canal cells in place, others with canal cells disorgan-

* The sexual organs are borne on different plants.

ized making an open canal to the *egg*, and others, perhaps, with an *embryo sporophyte* in the enlarged body. (¶ 391, fig. 331.)

14. *Demonstration.* From a mature capsule mount and show spores and elaters. (Fig. 11, *A*.)

C. MOSS (*Mnium cuspidatum*).

Examine plants with capsules attached. Observe the two connected plants :

1. The leafy stemmed plant or *gametophyte*. (¶ 55.)

2. The slender plant attached to its tip, the *sporophyte*, consisting of a wire-like stalk, the *seta*, enlarged above to form the hanging *capsule*. (¶¶ 67, 322.)

3. Boil for a few minutes in 5 per cent. potassic hydrate, rinse in water and gently pull sporophyte until it separates from the gametophyte. Observe the smooth pointed end which was sunk in gametophyte. If properly separated no sign of tearing can be seen. (Fig. 73.)

Examine gametophyte in water. Observe

4. The differentiation of the body into stem and leaves.

5. The brown hairs (*rhizoids*) about the stem, which attach plant to ground. Do they branch ? (¶ 62.)

6. The strength of the stem ; test it by breaking it with a lengthwise pull. Cut a thin transverse section and observe dark colored *mechanical tissues* in outer region. (¶ 63, fig. 68.)

7. The form and structure of the foliage leaves : note *midrib* of mechanical cells (test strength); *lamina* of one layer of cells large enough to be visible under lens ; *border* of mechanical cells, some projecting pretty regularly as *teeth*. (¶ 64, fig. 69.)

8. Smaller, scale-like leaves on part of the stem.

Examine sporophyte with mature capsule. Observe

9. The slender *seta*.

10. The thin yellow inverted *capsule*, from whose end a piece has fallen leaving it open. (¶ 322, fig. 72.)

11. About the edge of the capsule a fringe of pointed projections, *teeth*, curved inward, constituting the *peristome*. Break off these outer teeth and notice the pale fringed membrane within, forming the inner peristome or *endostome*. (Figs. 72, 231.)

12. Among these, or to be pressed out of capsule, many fine *spores*.

13. *Demonstration.* Cut off on a slide the end of the capsule as a ring, with peristome attached. Divide this ring into halves.

Holding one half with needle cut off the peristome close to capsule. This allows the teeth to float away from membrane. Turn other half with convex side up, cover all pieces, and show the peristome, endostome, and spores.

Examine young sporophytes of this or other mosses. Observe

14. The cylindrical form of the *embryo* sporophyte.

15. The *hood* covering its apex and carried up by it until the developing capsule forces it off. (¶ 401, fig. 338.)

16. The *lid* which falls off to open capsule.

17. Examine on young gametophytes the sex organs. Dissect with needles the tufts of leaves at apex of stem * and search for (*a*) Transparent oval sacs, the empty *spermaries;* and similar opaque greenish or whitish ones, in which sperms are still enclosed. (¶ 384, fig. 311, *B*). (*b*) Flask-shaped bodies, with a long neck and short stalk, the *ovaries.* These may always be found, withered somewhat, at the tip of a stem where a young sporophyte is developing. (¶ 391, fig. 331.)

Numerous hairs, *paraphyses*, of no known function, may be found intermixed with the sex organs.

19. *Demonstration.* With dissection as above, mount spermary and ovary. Show (*a*) in spermary, the stalk, the wall, the sperm cells ; (*b*) in ovary, the stalk, body, neck, canal, and egg.

IV. PTERIDOPHYTES.

A. MAIDENHAIR FERN (*Adiantum pedatum*).

I. The gametophyte.

1. Observe its shape and size ; the notch at the growing point (anterior end) ; the dying (posterior) end ; the thicker central region, with thin wings. (¶ 69.)

2. On the under side, a cluster of *rhizoids* near the posterior end.

3. Compare this plant with the thallus of *Marchantia.*

4. *Demonstration.* Mount a gametophyte underside up, and show (*a*) among the rhizoids the spherical *spermaries ;* (*b*) nearer the apex the chimney-like necks of the *ovaries.*

If gametophytes with young sporophytes attached are available, observe

* In some species the male organs form at the apex of the axis disk-like clusters, surrounded by leaves, the whole reminding one in form of a miniature sunflower-head, while the female organs occur in smaller numbers (3–6) in the bud-like clusters of leaves at the apex of other stems.

5. That the young sporophyte is fastened to the under side of the gametophyte. (¶ 72, figs. 76–78.)

II. The sporophyte.

Taking the underground parts in a dish of water, observe

1. The slender wire-like *roots*. How are they branched? (¶ 91 ff.) Where are they attached to the stem? Trace an unbroken one to the tip. The following points can only be seen on roots carefully gathered and cleaned. What difference of color near tip? Can you find many fine tangled *root hairs?* Where present? Where absent? (¶ 79.)

2. *Demonstration.* Cut a longitudinal median section of a root tip and show the tetrahedral (triangular in section) apical cell; the segments cut off from inner faces producing root tissues, those from outer face producing the root-cap. (¶ 77, fig. 83.)

Cut a transverse section of an old root, mount and observe

3. The outer brown *mechanical tissues* (also used for storage). (¶ 85.)

4. The central whitish tissue, chiefly the *stele*, in which the visible openings are the larger vessels. (¶ 81.)

5. In what position does the stem naturally stand? Observe its occasional *branching* (¶ 103); the surface covered with chaffy *scales* (¶ 128); the growing *apex* and dying *base*.

6. Its *nodes* and *internodes;* the nodes are indicated by the attachment of a single leaf at each; the internodes are the intervals between the nodes. How are the leaves placed? (¶ 119.)

Cut a transverse section of the stem and observe

7. The outer brown *mechanical tissues* (also used for storage). (¶ 129.)

8. The circular, oval, or C-shaped white tissues, most of which belong to the *stele*. Trace the course of the stele through at least two internodes by cutting a series of rather thick (1 mm.) sections, observing the mode in which the stele branches to pass out into a leaf. Cut also a longitudinal section through the base of a leaf stalk and trace course of stele. (¶¶ 130, 131.)

Taking a perfect leaf, dried under pressure, observe

9. The stalk or *petiole*, with its branches. Note the mode of branching; the petiole divides into two equal divergent branches; each of these forks, one branch carrying leaflets while the other again forks, and so on. (¶¶ 153, 155.)

10. The *hardness* of the mechanical tissues at surface of polished petiole.

11. The *leaflets.* Note (*a*) shape, as to outline and margin, comparing basal, median, and terminal leaflets of any branch; (*b*) the veins, containing branches of the stele; (*c*) the green tissues between the veins. (¶ 154.)

12. *Demonstration.* Strip off a bit of epidermis, mount and show (*a*) the irregular form of epidermal cells; (*b*) the intercellular openings with guard cells (*stomata*). (¶¶ 165, 166.)

13. *Demonstration.* Cut a very thin vertical section of a leaf at right angles to veins, and show (*a*) the upper and lower layer of cells forming the *epidermis*; (*b*) the green *parenchyma* cells with intercellular spaces; (*c*) the section of the *vein* composed of the stele with mechanical tissues above and below it. (¶¶ 167, 168.)

14. At the edges of the leaflets on the under side crescentic brown spots, *sori.* (¶ 323.)

15. Boil a leaflet for a minute in water. With a needle turn back a flap which covers the sorus, the *indusium;* observe that it is a specialized portion of the edge of leaflet.

16. On the under side of the indusium, a mass of yellowish spheroidal bodies, the *sporangia.* Scrape away most of them and notice the relation of their points of attachment to the veins.

Mount some of the sporangia and observe

17. Their shape; the *stalk* by which they were attached. (Fig. 401.)

18. The darker ridge, *annulus*, which serves to burst them when mature. (Fig. 401.)

19. Study the manner of *bursting.* Tear a bit of indusium from a dried specimen previously soaked in water, removing most of the sporangia. Allow it to dry while watching it with a lens, illuminating from above.

20. *Demonstration.* Mount sporangia and spores and show their structure, especially the annulus.

B. HORSETAIL (*Equisetum arvense*).

I. The gametophyte cannot be readily obtained, and differs from that of the fern mainly in having erect branches, with the sex organs on the upper side and always on separate plants.*

II. The sporophyte. Taking the underground parts in water, observe

* See Goebel, Outlines of Classification, figs. 210, 211; Campbell, Mosses and Ferns, fig. 220; Sachs, Physiology of Plants, figs. 425, 426.

1. The slender *roots* (all secondary); their places of origin. (¶ 76.) (Structure quite like ferns.)

2. The stem; its *nodes* and *internodes;* longitudinal shallow *furrows* and low *ridges.*

3. At each node a toothed *sheath* (representing a circle of leaves not distinct from each other), best seen on younger region.

Cut a transverse section of the stem; mount; observe

4. A circle of large *air-canals*, one opposite each furrow. Trace these lengthwise in an internode. Do they pass the node? (¶ 129.)

5. Within the circle of air canals, the tissues constitute the *stele.* Opposite each surface ridge, a cluster of small cells looking denser than adjacent tissues. These are the cut ends of the *vascular bundles.* (¶ 131.)

(If underground stems are lacking make out this structure in the aerial ones, which differ mainly in being hollow.)

Examine one of the flesh-colored aerial shoots in water (fig. 235, *A*). Observe

6. Similar distinction into *nodes* and *internodes.* Break the stem by a lengthwise pull. Where does it break? There is an *intercalary zone of growth* at the base of internode. (Compare leaves, ¶ 169.)

7. The large sheath at each node, the *leaves.* Each tooth represents a scale leaf. Note relation of teeth to ridges of stem and to those of sheath next above or below. (¶ 160.)

8. The different leaves near apex, separate, but whorled and crowded in a cone; these are the sporophylls. (¶¶ 324, 325, fig. 235.) Note the lowermost whorl united and forming a sort of collar.*

Dissect off several sporophylls in a small dish of water and observe

9. Their parts, the *stalk*, the *head;* hexagonal form of head due to crowding.

10. The six to ten thin sacs under the head and parallel with stalk, the *sporangia.* (Fig. 236.)

11. Tear open a sporangium. Leave the spores in a pile on one slide and mount a bit of the wall on another. In the latter observe the cells with thread-like spiral thickenings on the walls;

* This may be considered a primitive perianth (¶ 353) and gives added reason for calling the whole cluster a flower.

an arrangement to burst the sporangium when mature. (Fig. 238.)

Breathe on the dry mass of spores. Watch the squirming movements.

12. *Demonstration*. Mount a few spores in water and others dry, and show the *elaters*; strips of the outer walls of spores, loosened but wrapped around spores when moist, straightened out when dry. (Fig. 239.)

Examine the green branched *shoots* (fig. 235, *B*). Compare structure with other shoots, noting differences. Observe

13. *Profuse branching* and the arrangement of the branches and branchlets.

14. Cut a longitudinal section through the base of a branch. Observe that the branches arise from the stem *above* the origin of leaves and burst through the sheath.

15. That the nutritive work depends on the stem, not on the leaves, which lack green tissue.

16. The roughness of the surface. Rub branches on a metal surface and observe that they scratch it, on account of silica in walls of surface cells.

C. SELAGINELLA (*S. rupestris*).

I. Gametophytes, male and female, are extremely reduced, scarcely bursting the wall of the spores producing them. See ¶¶ 384, 392, figs. 315, 333.

II. Sporophyte.

Examine in water an entire plant. (If previously dry it should be boiled for a few minutes in water.) Observe

1. The yellow thread-like secondary *roots* arising at various points from the stem. (Structure like fern.)

2. The branched *shoots*; note method; lateral branches arising from side of mother shoot, i.e., monopodial branching.

3. The crowded *foliage leaves*. How arranged? (See p. 97.)

4. The *sporophylls*. Search for ends of branches having leaves in four vertical ranks. Compare form of these leaves with foliage leaves. Observe

5. In their axils large yellow sacs, the *sporangia*; some containing

6. One to three large spores, the *megaspores;* more abundant than similar sporangia containing

7. Numerous small spores, the *microspores*. Microsporangia are usually at tip or base of spike and are often difficult to find if material is not collected at proper season. (¶¶ 326, 327.)

V. SPERMATOPHYTES.*

A. PINE (*Pinus sylvestris*).

Examine a shoot showing at least the growth of present year and that of the preceding. Observe

1. Two kinds of axes: (*a*) the *main axis* of the shoot, with unlimited growth, now terminated by a conical bud; (*b*) the very short lateral axes of limited growth, *dwarf branches*, each bearing two *needle-leaves*. (¶ 110, fig. 101.)

2. The six forms of leaves. Study the shape and structure of each. (*a*) the slender green leaves, *needles*; (*b*) the *scales* closely covering the older parts of the stem, in whose axils arise the dwarf branches carrying the needle-leaves; (*c*) the thin broad *scales* on the dwarf branches, enwrapping the bases of the needle-leaves (best seen about the leaves on the young shoot); (*d*) the *scales* protecting the apical bud (¶ 160); (*e*) the two forms of sporangium-bearing leaves, *sporophylls*, in the two sorts of flowers (see further 4 and 9).

3. Dissect the scales carefully from a large *terminal bud* and compare the interior parts with those of the shoot which bears it. Can you make out the corresponding members? If not, it is because the bud is too young. Use a bud taken from the tree in summer or autumn and these points can be seen best. What is a bud? (p. 85.)

4. Examine the sporophylls. Observe the two kinds: (*a*) Numerous oval clusters of yellowish bodies, the micro-sporophylls or *stamens*, about the base of the young shoots (fig. 101), now called a *staminate flower*; (*b*) a single cluster of mega-sporophylls about the apex of one or two short lateral branches arising just below terminal bud of a young shoot and extending a little beyond it, forming the *pistillate flower*. (¶¶ 331, 344.)

5. Study the arrangement of the staminate flowers on the axis. Compare the position of each cluster of sporophylls (flower) with

* In this group the sporophytes only can be studied without the compound microscope. For gametophytes see *demonstration*

that of the dwarf shoots on the upper part of the same axis. What is a flower? (p. 236.)

6. Dissect off a single micro-sporophyll (stamen) from one of the staminate flowers. Observe the broad short stalk; the thin upturned end; the two large sacs, *sporangia*, on the under side. Tear open these and observe the innumerable small spores, *microspores* (or pollen grains).

7. *Demonstration.* Mount mature microspores in water and show (*a*) the spore itself (the central body) with two bladdery enlargements of the outer wall to secure buoyancy in air; (*b*) the immature *male* gametophyte inside, consisting of two cells, the smaller representing the vegetative part (a mere rudiment) and the larger the *spermary*, simple by reduction. (¶ 385.)

8. Examine a pistillate flower. Observe that it shows from the surface two kinds of leaves: (*a*) thin ones with toothed edge, the so-called *bracts*; (*b*) thick fleshy ones with a prominent point, the *carpels*. These are probably two parts of one structure, the *sporophyll*, which is deeply divided; but there is wide difference of opinion as to the exact nature of the bracts and carpels.

9. Dissect out a carpel and observe (*a*) the broad attachment; (*b*) the ridge on the upper side (*keel*) extending into a prominent point; (*c*) the two enlargements on the upper side near the base, the *ovules*, and their oblique position. The ovules consist of an *integument* and a *sporangium* containing a single megaspore. Note the opening in the integument (*micropyle*) at the end nearest the base of the carpel, with two prolongations right and left. (Fig. 246.)

10. Examine a year-old cone. Observe the excessive growth of the carpels as compared with the bracts. Can you find the latter by cutting the cone smoothly lengthwise through the center? Note the woody texture of all parts. (¶ 404, fig. 341.)

11. Dissect out an entire carpel. Observe the obliquely placed ovules (Fig. 342).

12. Cut a thin longitudinal section of the ovules and the carpel. Observe the *sporangium* surrounded by the *integument* prolonged beyond it at the orifice; inside the sporangium a cavity, the interior of the *megaspore*, now partly filled with the *young female gametophyte.* (Compare fig. 319.)

13. *Demonstration.* In a similar section show these parts under compound microscope, especially (*a*) the female gametophyte, growing inside the spore which has not escaped from the sporan-

gium; (*b*) microspores lodged about the mouth of integument, the spermary often forming a tube. (¶ 386.)

Examine a 2-year-old (mature) cone. Observe

14. The extreme woodiness of the cone, especially the carpels which are spread apart when dry. (¶ 404.)

15. On the upper surface of some carpels, two thin wing-like scales, with a *seed* attached.

16. Time the fall of winged seed from the extreme height to which you can reach. Time its fall after removing wing. How will this aid in distributing seed? (¶ 492.)

Bisect a seed lengthwise, parallel to flatter faces. Observe

17. The firm *seed-coat*, which is the integument of the ovule grown and ripened.

18. Enclosed by the coat a white tissue loaded with starch and oil, the *endosperm*, which is the enlarged female gametophyte. In the center of this the *embryo* sporophyte which grew from one of the eggs produced by the female gametophyte, after the egg was fertilized. Note that the tissues of the sporangium have disappeared, having been crowded and absorbed. (¶ 403.)

19. Dissect out the embryo from another seed. Observe that it is already differentiated into a slender *stem*, and six *primary leaves* about its apex. (Fig. 339.)

B. MARSH MARIGOLD (*Caltha palustris*).

1. Examine the roots. Observe (*a*) their surface, wrinkled from shortening; (*b*) their structure.

2. Cut a transverse section as in fern; observe that mechanical tissues are wanting.

3. Bisect longitudinally the base of a plant. Observe, as shown by the origin of leaves, the variable length of internodes; at base the internodes are very short so that leaves are crowded; in the middle the internodes are long and leaves distant; above, the internodes become shorter until, in the flower, they are not developed and the leaves are very much crowded. (¶ 119.)

Study one of the well developed foliage leaves (¶ 150). Observe

4. The broad rounded blade with slight branches (teeth) at the margin.

5. The long slender stalk, petiole, gradually passing into

6. The sheathing base, in upper leaves branched to form two stipules.

7. Examine and compare the various forms of leaves: (*a*) the lowest, having sheathing bases without petiole or blade, passing gradually into (*b*) the best developed foliage leaves; (*c*) these near the flowers losing petiole and diminishing blade, becoming *bracts;* (*d*) the yellow *perianth* leaves; (*e*) next within these the yellowish *stamens* (micro-sporophylls); (*f*) the flattened pod-like green *carpels* (mega-sporophylls) each forming a *simple pistil.* (¶¶ 160, 161.)

8. Bisect a flower lengthwise. Observe the three sorts of leaves, perianth, stamens, and carpels; their relation to each other and their insertion separately on the enlarged stem, the *torus.* Separate some from an old flower and note the scars left by their fall. (¶ 330.)

9. Are perianth leaves similar, or of two sorts? (¶ 354.)

10. Dissect off a stamen. Observe the two parts: (*a*) the slender stalk, *filament*, and (*b*) the enlarged part, *anther.* Note in the anther the two lobes, each with a shallow groove marking the position of the two pairs of *sporangia.* Tear open the sporangia with a needle and observe the innumerable *microspores* (pollen grains) which they contain. Examine a naturally bursted anther and determine how they open. (¶¶ 345–348.)

11. *Demonstration.* Cut a thin section of an anther from a bud and show (*a*) the four sporangia, in pairs, entirely distinct, and the point at which they become confluent as they burst; (*b*) the pollen grains. (¶ 351.)

Dissect off and examine a pistil. (¶ 338.) Observe

12. At the apex the roughened area, the *stigma* (¶ 336), sessile (¶ 337) upon

13. The enlarged part, the *ovulary* (¶ 335). Observe its flattened form and the groove along one edge. Split it along this line, flatten it out carefully and note the *ovules* attached to the edges. (¶ 343.)

14. Cut several transverse sections of the pistil and observe the thickened edges of the carpel, forming the *placenta*, to which ovules are attached. Compare sections. Are all ovules attached to same edge?

15. *Demonstration.* Prepare a longitudinal section of an ovule of a lily and show the two integuments; the sporangium, enclosing the single megaspore, or *embryo sac.* (¶¶ 340, 394.)

Study and compare the flower and leaves of the sweet pea (*Lathyrus odoratus*), apple, fuchsia, and garden lily.

For the study of primary roots and root hairs, primary stem and primary leaves, germinate Indian corn, scarlet runner or any bean, in clean damp *pine* sawdust, and grow until plants are several inches high, watching stages of development.

For forms of stems examine white potato (tuber); onion (bulb); Indian turnip or Cyclamen (corm); morning glory or hop (twining); white clover (creeping).

For structure of stems, study Indian corn (monocotyledon, with no secondary thickening), cucumber or pumpkin (dicotyledon, with no secondary thickening), and young sunflower (dicotyledon, with secondary thickening). Compare transverse sections.

For lenticels and the formation of periderm, examine the twigs of plum, cherry, elder or box-elder.

For buds examine large winter buds of hickory, horsechestnut, or poplar.

Part II: Physiology.

1. *To show the existence of turgor in the individual cell.* (¶ 188.)

Mount a bit of *Spirogyra* under microscope; observe position of chlorophyll bands. Irrigate with 5 per cent. solution of salt and note effect.

(If *Spirogyra* is not at hand use hairs on stamens of *Tradescantia*; or the epidermis, filled with purple cell sap, from the under side of the leaves of the cultivated *Tradescantia* ("wandering Jew"); or the hairs of geranium leaves.)

2. *To show effect of turgor of cells on rigidity of young parts containing no mechanical tissues.* (¶ 188.)

Remove carefully a young plant with vigorous primary root grown in sawdust or sand. Lay in water for a few minutes. Note rigidity. Transfer to 5 per cent. salt solution for a few minutes. Again note rigidity. What has happened? Remove to water again for 15 min. What is the result?

3. *To show the existence of longitudinal tensions of tissues due to unequal growth or turgor.* (¶ 259.)

A. Cut a young internode of elder 10 cm. long, making ends as square as possible. Measure accurately. Remove wood all around and measure pith. Place pith in an atmosphere satu-

rated with moisture and measure after 1 hour. Compare measurements. (If elder is not at hand use young shoots of grape, wild or cultivated.)

B. Split a scape of dandelion lengthwise with a sharp knife into four strips. Note immediate effect upon their form. Lay the strips in water for a few minutes. Observe form. Transfer them to 5 per cent. salt solution. What effect? What causes these changes of curvature? (The young stems (hypocotyls) of castor bean may be substituted for dandelion scapes but are not so responsive.)

4. *To show the existence of transverse tensions of tissues due to unequal growth.*

A. From a piece of willow or poplar stem separate a ring of bark 1 cm. wide, slitting it on one side only, taking care not to stretch it. Keep it in a moist atmosphere for a few minutes, and then replace it. Does it meet about the wood?

B. Cut a slice about 2 mm. thick from the end of a stalk of rhubarb. Bisect this and keep the halves for a few minutes in a moist atmosphere, then place severed edges together. Do they touch throughout?

5. *To show the location of root hairs and especially their adhesion to soil particles.* (¶¶ 79, 200.)

Germinate wheat in sand and when seedlings have several strong roots dig up carefully; shake sharply in water; note where soil clings most tenaciously. Brush away most of this with camelhair brush and examine a bit of this part of root under a low power of microscope. Observe distortion of root hairs, and particles of sand partly embedded in them.

6. *To show excretion of acid salts by roots.* (¶ 202.)

Fill a wide-mouthed bottle holding 250 cc. with tap water; add 2–3 drops of ammonia and several drops of phenolphtalein.* If the water does not now remain pink add a drop or two more of ammonia. Select a vigorous seedling bean grown in sawdust; rinse roots well to remove impurities.

Cut in two a cork which fits the bottle; in the halves cut two corresponding notches of such size that with a little cotton for packing the plant will be firmly held. Place the plant with

* An indicator for acids, colorless when a fluid in which it is dissolved is acid, rose pink or darker when alkaline. For use the crystallized phenolphtalein is dissolved in alcohol.

enough cotton to secure it in the cut cork and set in bottle with roots immersed.

As the plant grows from day to day watch for the disappearance of color in the solution, which will indicate when the alkaline fluid has become acid. Arrange a control experiment in exactly the same way, but without plant. Surround each bottle with opaque shade of heavy paper, to avoid effect of light on the roots and fluid.

7. *To show the corrosion of carbonate of lime by the carbonic acid excreted by the roots.* (¶ 202.)

Cover a polished marble slab to a depth of 5 cm. with clean sand, in which plant corn or beans. After the plants are 10–15 cm. high, remove sand carefully and rinse off the marble. Examine the surface by reflected light. A little graphite rubbed into lines etched by roots will make them more readily visible.

8. *To show root pressure as a factor in the movement of water in plants.* (¶ 205, fig. 172.)

Cut off the stem of an actively growing plant (plants of castor bean and tomato 25–30 cm. high are especially recommended) a short distance above the soil and fasten tightly to the stump, by means of rubber tubing, a piece of glass tubing a meter long, and about the diameter of the stump. Add enough water to rise 10 cm. above the rubber connection. Keep roots well watered and mark the height of the water in tube from time to time until it reaches the top or begins to fall. Does the water rise from the first?

A more satisfactory record may be reached by attaching to the stump a T-tube as shown in fig. 172. To the horizontal arm attach a mercury manometer. (A manometer may be readily constructed by bending a glass tube, about 5 mm. diameter (3 mm. bore) and 80 cm. long, upon itself 30 cm. from one end, so that it forms a U with unequal legs 3–4 cm. apart. Bend 5 cm. of the end of the short leg at right angles, in the plane of the U. Tie the legs to a piece of cork between the legs near top, so that the tube will not be easily broken by the leverage of the legs on the bottom bend.) Fill the space between stump and mercury with water. In the third arm insert a short tube drawn out to a slender point to permit the escape of air and extra water. Seal this with flame after filling. There must be at least 15 cm. of mercury in U portion of manometer. At beginning mark, with a bit of gummed paper, height of mercury in each leg; measure difference at intervals thereafter until mercury begins to fall.

9. *To show that water is not absorbed by leaves in quantity adequate to supply evaporation.* (¶ 196.)

Cut off a vigorous shoot of a plant with abundant foliage; close end of stem with grafting wax; expose to sunlight until slightly wilted; then immerse it in water. Does the plant recover its turgidity?

10. *To show that many leaves are not wetted by water.* (¶ 210.)

Immerse various sorts of leaves in water. Does the water wet the surface? What is the cause of the silvery reflection of light from the surfaces of some? What relation does this repulsion of water have to blocking of stomata by rain?

11. *To show the loss of water by evaporation.* (¶ 208.)

Clean and dry the surface of a pot in which a thrifty single-stemmed plant is growing; close the hole in the bottom with a cork; with a brush paint the whole surface with a thick layer of melted paraffin. Cut out a piece of stiff paper which will fit around stem and just cover the soil in pot. Using this as a pattern cut a cover for the soil from a sheet of lead; slit the cover from the central hole to circumference; adjust it around plant and cement all cracks with grafting wax.* Weigh. Weigh again at intervals of 24 hours, for 4 days.

12. *To show the variation in the rate of evaporation due to the difference in structure of the organ.* (¶¶ 209, 438.)

Compare as shown by shrinkage or by loss of weight. (*a*) Through cork tissue and without it. Take two potatoes; peel one; expose side by side; compare day by day. (*b*) Through skin. Compare in same way two apples. (*c*) Through stomata. Take three equal leaves of oleander; of one close the stomata (which are on under side only) with a thin coat of grafting wax, or cocoa-butter melted and brushed on (taking care not to kill cells by having wax too hot); coat the upper surface of second in same way; leave third uncovered. Compare day by day.

13. *To show the conditions affecting evaporation.* (¶ 210.)

Construct a potometer as follows: Bend the central stem of a T-tube until it is parallel with the cross piece. Fit into the lower opening of the straight leg a capillary tube 30–40 cm. long, with 3 cm. of each end bent at right angles to the main part and in opposite directions. Into the bent leg fit a shoot of a thrifty plant cut off under water, at the same time filling the T-tube with

* Or the pot can be set in a tin vessel which it fits and the lead cover luted to this.

water. (To accomplish this bend the shoot to be cut off so that the place of the cut is submerged in a deep pan of water. Fit it in tube without exposing cut surface at all to air.) Dip the lower end of the capillary tube in water and allow apparatus to stand until capillary tube fills with water. Remove the water for a moment and allow a bubble 1 cm. long to enter; time it as it moves between a series of equidistant marks on capillary tube. Try the rate under various conditions of light, temperature, and moisture acting on shoot.

14. *To show the lifting power of evaporation.* (¶ 207.)

Cut off under water a shoot from a thrifty plant; fasten it air-tight in the end of a piece of glass tubing 30 cm. long, of appropriate diameter, by means of a piece of rubber tubing slipped over the end of the stem, taking care not to expose the cut end to air. Fill glass tube with water before fitting in plant; erect the whole with lower end of tube dipping in a cup of mercury. Set in light and note height of mercury in 1–48 hours.

15. *To show loss of liquid water when absorption is great and evaporation slow.*

Grow seedlings of wheat or oats until 5–10 cm. high; then cover with a glass bell for an hour or two. Where do drops of water appear? Why?

16. *To show roughly the path of evaporation stream in woody plants.* (¶ 206.)

A. From a leafy shoot of a woody plant remove a ring of bark 5 mm. wide. Protect the exposed surface against drying with grafting wax. Observe whether the leaves wilt or not, and if they wilt, the time required.

B. With a knife or fine saw cut a little over half through the stem of a plant of the same sort used in *A*; 1 cm. above this cut make a similar one on the opposite side. The two must be so placed and of such a depth that all the tissues are severed. Support the branch or stiffen it against breaking by bandaging it with strips of wood. Make same observations as in *A*. Examine the pith. Is it alive? Does it contain water? In what tissues, therefore, do you infer water travels to leaves?

17. *To show restoration and maintenance of an interrupted evaporation stream.*

Fit a well wilted shoot into the short arm of an unequal U-tube filled with water to the level of the short end. Allow it to stand for half an hour. Does the shoot recover? If not, pour mercury

into the longer arm until it stands 10 cm. above its level in the short arm. Does the shoot now recover turgor? Why? Allow it to stand for some days. Does the level of the mercury change?

18. *To show in what tissues food most readily travels.* (¶ 235.)

Girdle as in experiment 16 *A* a shoot of willow. Cut it off 5 cm. below ring. Place shoot in water. After some weeks note where new roots are formed. Why?

19. *To show the permeability of stomata for air and their communication with the system of intercellular spaces.* (¶¶ 167, 227.)

Fasten a leaf with a long petiole air-tight in a rubber cork, through which also passes a short glass tube. Fit the cork into a bottle holding sufficient water to cover end of petiole. Attach a filter pump or air pump to glass tube. Observe whether air bubbles leave the end of the leaf stalk.

Reverse the leaf, so that the blade is immersed, and make same observation. Where do bubbles appear? Is there any difference between upper and lower sides?

20. *To show the depth to which light may penetrate green tissues.* (¶ 231.)

Take a cylindrical pasteboard or metal tube, closed at one end and having a cover which will fit over the closed end. In the end and in the cover cut corresponding holes 1 cm. in diam. Mark side and cover when in place so that holes can be made to coincide. On the bottom place a part of a leaf which will cover hole. Slip on cover and observe whether light is transmitted through leaf. Add successive pieces of leaf until no more light passes. What is the color of last light seen? The examination must be made with direct sunlight, and light *completely* excluded from the eye except that which passes through the instrument.

21. *Method for detecting considerable quantities of starch in plant organs.* (¶ 233.)

Boil a few leaves of various plants for a few minutes. Place in alcohol at about 60° C. until all chlorophyll is dissolved.* Bring the leaves into a tincture of iodine, diluted to a bright brown, for half an hour. The leaves or parts containing starch will become bluish, dark blue, or black, according to amount of starch present.

22. *To show that manufacture of starch occurs only in cells directly illuminated.* (¶ 231.)

* Do not heat over open flame, but set bottle, loosely corked, in a vessel of hot water.

Darken portions of some leaves of a plant previously found to show starch in its leaves (sunflower, bean, tomato, or nasturtium) by attaching two plates of cork on opposite sides by means of two pins driven through both and the leaf. On the afternoon of the following day, if sunny, cut off the leaves and test for starch. What has become of starch in cells under the cork?

23. *To show that oxygen is a by-product of photosyntax.* (¶ 250.)

Collect the gas mixture evolved from a vessel full of aquatic plants by inverting over them a funnel to whose tip is connected a test tube filled with water to be displaced by the rising gases. Keep the plants in sunlight. When the tube is filled, test the contents for oxygen by inserting a glowing splinter.

24. *To show the effect of light and temperature on photosyntax, using the rate of evolution of oxygen as an index.*

Fasten a shoot of a water plant (*Elodea*, *Myriophyllum*, or *Ceratophyllum*) 10 cm. long to a glass rod and immerse in tap water so that the cut end is uppermost. Set in sunlight and observe the bubbles rising from the end of stem.* Determine rate at which they rise by counting the number given off in a certain short time. Continue the observation until the rate is approximately uniform. Shade the shoot and determine rate. Return to sunlight and determine rate. Put a piece of ice in the water and determine again.

25. *To show the digestion of starch by diastase.* (¶ 237.)

Powder a handful of malt in a mortar or obtain ground malt. To 25 grams of the powder add 100 cc. of water; stir well together; allow mixture to stand (with occasional stirring) one to two hours; filter; preserve the filtrate. Take 1 gm. of starch and rub it up in a dish with 5 cc. water; pour this into 95 cc. of boiling water, stirring as it enters. With 25 cc. of this paste mix thoroughly 5 cc. of the filtrate (which contains diastase extracted from the malt). Test a small portion of the mixture at once for starch by adding a few drops of tincture of iodine, and similar portions at intervals of half an hour until starch reaction ceases. Taste the remaining paste. Into what has the starch been converted?

26. *To show evolution of CO_2 by respiration of leaves and flowers.* (¶ 239.)

* If several bubbles arise at once, remove shoot from water, dry the cut end of stem with filter paper and coat it with a thin layer of grafting wax; then perforate this wax with a fine needle point so as to offer one exit for gases.

Provide a piece of plate glass and a bell jar with ground rim, of suitable size to cover a blooming plant growing in a pot. Alongside the pot place a shallow dish of baryta-water ; cover both with the bell, daubing its edge with vaseline to make contact with glass plate air-tight. Place in darkness. Note film of barium carbonate on surface of water after a day. Conduct a control experiment, identical but for the absence of plant. Is more or less barium carbonate formed? Why darken?

27. *To show evolution of CO_2 by respiration of seedlings.*

Fill a wide-mouthed glass jar or bottle of 1 liter capacity one-third full of peas and beans which have been swollen for a day in water, then rinsed thoroughly in 5 per cent. formalin and again rinsed in water. Cork or cover tightly. After 24–48 hours remove cover and thrust in a burning match or candle attached to a wire. If CO_2 has been produced it will extinguish flame. Test also by lowering into jar a vessel of baryta-water. If precipitate or film forms it shows presence of CO_2.

28. *To show the evolution of heat during respiration.* (¶ 248.)

Take three-fifths the amount of dry wheat required to fill two 3-inch flower pots ; swell in water over night ; rinse one half in formalin as above ; kill the other by boiling in water for five minutes. Stop bottom hole in pot with a cork; fill one with dead, the other with living seeds, and bring the two to same temperature by running water through the dead and hot one. Insert a thermometer in the center of each mass of seeds ; place both under one box or bell jar. Observe changes of temperature for two days.*

29. *To measure the rate of growth in length.*

Construct an auxanometer as follows : Take a board 30 cm. square, a common spool, a wheat or oat straw 35 cm. long, and a piece of glass tubing 5 cm. long, which will just allow spool to revolve easily on it. Close one end of the glass tube by holding it in the flame of a Bunsen burner ; when hot spread it enough to stop spool from passing over end, by pressing it endwise against a piece of iron. With a fine saw cut a section 5 mm. thick from middle of spool, thus making a wheel. File a groove in edge of this wheel, deep enough to carry a thread. Slip wheel on glass tube and fasten it in board near lower left corner so deep that spool-wheel will revolve smoothly but have no un-

* Compare thermometers previously to see that they register alike ; if not ascertain the correction. Greater differences in temperature of seeds will be observed if pots are surrounded with cotton batting.

necessary play. On the board, with hole for glass tube as a center, mark an arc of 90 degrees. The radius of the arc should be a multiple of the radius of wheel. Divide arc into half centimeters. Attach wheat straw to wheel as a pointer.

To the tip of a growing seedling bean fasten a thread by a slip noose. Pass thread over wheel once and to its free end attach a light weight—just enough to turn wheel and pointer when plant is lifted. Set pointer at 0 and at intervals read the multiplied growth. By taking observations at regular intervals determine the rate of growth of stem for a week. What regular variation can you discover?

30. *To show the necessity of respiration for growth.* (¶¶ 242, 245.) Germinate a number of beans in sawdust. Select eight with straight roots about 2 cm. long. Clean and dry the surface slightly by brushing with frayed edges of strips of filter paper, taking care not to expose roots so long that they are injured by dry air. With a very fine sablehair brush and thick Chinese (or waterproof black drawing) ink, mark each root by distinct lines into ten spaces 1 mm. apart, commencing with tip. This can be done most conveniently by pinning the seedling to a strip of soft wood and laying alongside the root a ruler whose graduated edge has been blunted by a plane until it is about 2 mm. thick.

Pin half the seedlings to a strip of soft wood set into a jar partly filled with wet sawdust, so that the roots will be vertical in damp air. Put the other half into a similar jar and cover them with water recently boiled and cooled. After 24 hours, remeasure and compare total growth. (See also exp. 31.)

31. *To determine the zone of maximum growth in roots and stems.* (¶ 258.)

A. Observe the four seedlings of exp. 30, whose roots grew in moist air. Which spaces grew most?

B. Mark several upper internodes of a bean plant in a similar way, but at 5 mm. intervals. After 48 hours observe how many have elongated and which have grown most?

32. *To show the effect of gravity as a stimulus on roots.* (¶¶ 287–290.)

Arrange the marked root of a seedling bean as in exp. 30, except that the root is horizontal, and a pin just above the extremity marks its position. After 24 hours observe curvature and which spaces have become curved. Compare with those which have grown most.

33. *To show the effect of gravity as a stimulus on growing regions of upright leaves and stems.* (¶¶ 287–290.)

A. Support an onion, roots down, in a vessel of water so that it is half immersed, until the leaves are about 10 cm. long. Then turn it so that leaves are horizontal and observe where curvature occurs.

B. Cover the bottom of a deep dish about 25 cm. long with a layer of wet sand, and bank this against one end to the top. Into this bank stick horizontally several grass stems having at least one node ; cover with a glass plate. After 24–48 hours observe curvature. Cut a longitudinal section of the node and observe the part of the leaf-sheath in this curvature.

34. *To show the effect of direction of light as a stimulus on leaves.* (¶ 285.)

Set a potted plant (geranium, sunflower, nasturtium, or mallow) in the dark for 24 hours ; then place it before a window, shading it so that light reaches it chiefly from one direction. Mark certain leaves and record the position of the plane of the blade ; 24 hours later observe the position and compare with first.

35. *To show effect of direction of light as a stimulus upon stems and roots.* (¶ 285.)

Grow seedlings of white mustard thus : Tie loosely over the mouth of a jelly-glass a double piece of fine bobbinnet; fill vessel with tap water to the net, on which place seeds ; set in dark, replacing water as it evaporates, until seedlings are 3 cm. high, with roots as long or longer. Then place in a box, blackened inside, into which light is admitted, through a hole 4–5 cm. in diameter, at right angles to stems and roots. Observe curvatures 24 hours later.

36. *To show effect of intensity of light as a stimulus on certain leaves.* (¶ 297.)

Observe the position of the leaflets of white, red, or sweet clover, bean, locust, or oxalis at 3 P.M., 6 P.M., at dusk (or after nightfall by using a lantern) and at 8 A.M. In the morning darken with a box a plant showing these movements. After an hour or two, observe the position of leaflets.

37. *To show effect of contact as a stimulus to tendrils.* (¶ 293.)

Stroke with a pencil the concave side of the tip of a tendril of passion vine, squash, wild cucumber, or balsam-apple, on a warm day or in a hothouse, and observe curvature which follows in a few minutes.

APPENDIX II.

DIRECTIONS FOR COLLECTING AND PRESERVING MATERIAL.

Those who cannot collect the plants they require can order them from the Cambridge Botanical Supply Co., 1286 Massachusetts av., Cambridge, Mass. Orders should be placed in advance of the collecting season to insure obtaining the material.

Pleurococcus.—For this and similar one-celled algæ, collect pieces of shaded fence boards near the ground, or flakes of bark from the north side of trees in groves and parks, which show a bright yellow-green color. These may be preserved dry.

Oscillaria.—Search in drippings about watering troughs, city gutters where water stands, or any open drain which contains organic matter decaying in stagnant water. A glass jar or aquarium in which water plants have decayed will usually contain this plant. It may be recognized by its bluish or blackish green color, and often occurs in coherent films or thicker masses. It may be obtained fresh at any time of year, either out doors or in the laboratory.

Rivularia.—Collect in midsummer or later the larger water plants to whose leaves and stems adhere jelly-like lumps of a dirty green color, from the size of a pinhead to 1–2 cm. in diameter. The margins of lakes, pools, and slow streams furnish the best localities.

Nostoc colonies form similar jelly masses, commonly larger and free floating or attached. Preserve both like the following.

Spirogyra or **Zygnema.**—Search in spring or early summer in slow streams fed by springs. It will be recognized when in vegetative condition by rich green color and slippery "feel." Under the microscope the form of the chloroplasts will show the genus.

(See ¶ 25.) When conjugating it often loses the deep green and becomes yellowish, and the filaments seem to be double.

This condition can be recognized under the lens. *Spirogyra* may often be obtained all through the year in pools and springs. It should be preserved in the following solution: Camphor water 50 cc.; water 50 cc.; glacial acetic acid 0.5 cc.; copper nitrate 2 gm.; copper chloride 2 gm.

Cladophora.—Species of this genus may be found attached to sticks and stones at the edge of lakes or pools. It often covers these completely with a thick mat of long, yellowish green, branched filaments. It may be found throughout the growing season. For winter use preserve in same solution as above.

Chara.—Several species are common in shallow ponds and lakes, in water 0.2–1 meter deep, rooting in the mud, often in company with *Myriophyllum* and *Ceratophyllum*, two seed plants, the latter of which may readily be mistaken for it by novices. But these plants are usually bright green while Chara is dull or dirty green, or even whitish (especially when dry) from the coating of lime, which also renders it brittle and harsh to the touch. Careful inspection of its form and a section of the axis at once enables one to recognize it. (See figs. 35. 37.) Specimens should be gathered when the spermaries on the lower branches ("leaves") are orange. Pull up the plants carefully, wash off as much as possible of the mud which clings to the delicate, colorless rhizoids. The basal part of the axis should be put in a separate jar from the rest. Put a few plants into 2 per cent. chromic acid, and allow them to remain 24 hours to dissolve off lime with which they are incrusted. After pouring off the acid and rinsing them thoroughly, soak them in a large vessel of water for 24 hours, changing water several times (or allow water to run over them slowly for six hours) to remove acid. Preserve in 70 per cent. alcohol. Plants may be preserved in formalin or 70 per cent. alcohol, in long jars so as to entangle them as little as possible. If brittle from alcohol (as they often are) before removing them from jar for distribution pour off alcohol and cover with water for a few minutes.

Polysiphonia.—All species are marine, and any common species will serve. They are found in reddish brown, feathery tufts 2–10 cm. high, on other larger sea-weeds, or on piles and stones, about low-water mark. They collapse completely when withdrawn from the water.

The plants should be fixed in one per cent. chromic acid (or in a saturated solution of picric acid in sea-water) for 12-24 hours, washed in sea-water as described for *Chara*, and hardened in 40, 60 and 80 per cent. alcohol successively, remaining in each 6–24 hours. They may be preserved in the latter. They may also be preserved in formalin.

Fucus.—All species are marine and any one will serve. The commonest is *Fucus vesiculosus* (fig. 42), which may be found on rocks between tide marks. It is of olive-brown color, with swollen tips to many of the branches, and bladders in pairs along the thallus. Plants may be obtained fresh at almost any season. Various species of brown sea-weed may be found fresh at the fish stores of all large cities, whither they are sent as packing.

Mucor or **Rhizopus.**—Saturate a piece of bread with water and keep it under a bell jar, in a warm place, for a few days. Several species of molds will appear, the most common of which is the black mold, *Rhizopus nigricans*. This may be recognized by its white fluffy mycelium, on which arise tufts of erect hyphæ developing at tips spherical sporangia, at first white, later black. These tufts occur at intervals along a stolon-like hypha. The same mold may be found on rotting vegetables and fruits, especially sweet potatoes and lemons, and may be raised more rapidly on bread by sowing spores. It will be followed by the green mold, *Penicillium glaucum*, and often later by other species. Since the plants may be grown promptly, the material used should be living.

Microsphæra or **Uncinula** or **Erysiphe.**—Any species of mildew will answer. *Microsphæra* grows everywhere on the leaves of the cultivated lilac. *Erysiphe* is abundant on the leaves of blue or white vervain (*Verbena hastata* and *V. urticæfolia*) and many Compositæ. *Uncinula* attacks leaves of many willows. About midsummer, when the fungus has a white powdery aspect, gather leaves and dry them under light pressure. Later, gather leaves of the same species showing yellow and black dots (the fruits) on the mycelium. Preserve in the same way.

Cystopus portulacæ.—This species is abundant throughout the summer on leaves and stems of purslane (*Portulaca oleracea*) which grows in every garden and cornfield. Another species grows in late spring on shepherd's-purse (*Capsella bursa-pastoris*) and another on the pigweeds (*Amaranthus* sp.). Any one will answer. The species on *Capsella* (*Cystopus candidus*) only oc-

casionally forms resting spores in that host. They may be found in abundance in the flowers of radish which become much enlarged and distorted when this fungus is parasitic thereon. All species may be known by the white blisters formed by lifting the skin of the host. Preserve in formalin or alcohol leaves and stems of host bearing blisters. Some may also be dried.

Peziza.—The cup fungi grow on earth or fallen rotting leaves, twigs or trunks, in woods. The fructifications may be at once recognized by their cup-like form. The inner surface of the cup is often bright colored, red or orange, brown or black. The mycelium is hidden in the substratum. They may be collected in spring and summer and preserved in formalin or 70 per cent. alcohol.

Lichens.—Any common foliose species which forms apothecia abundantly will answer. A bright gray species with black apothecia (*Physcia stellaris*) is abundant on tree trunks, as is also a yellowish species with orange apothecia (*Theloschistes polycarpa*). These may be collected at any convenient time, and kept dry. Besides these, collect other foliose forms; also species of *Cladonia* growing on the ground, with body much lobed and the apothecia coral-red knobs on upright gray stalks; also species of *Usnea*, clothing the branches of trees with gray-green shrub-like or hair-like tufts.

Mushroom.—Any species with cap and gills will answer. They may be found in woods throughout the summer and especially in late summer or autumn during a rainy season following drought. Only the fructification need be collected. Select a small firm species with well defined stalk, cap and gills. Collect fructifications in all stages of development from young to mature. Preserve as soon as gathered in formalin or 70 per cent. alcohol.

Other Hymenomycetes.—Collect fleshy cap fungi with hanging points instead of gills (*Hydnum*, fig. 217), or intersecting plates forming tubes (*Boletus*). Preserve these as mushroom. Collect also the woody bracket fungi (*Polyporus*, fig. 218), which grow on rotten trees and fallen limbs, showing innumerable fine tubes underneath. Preserve dry. Also the much branched firm-fleshed *Clavaria* (fig. 215). Preserve as mushroom. All will be found in damp woods.

Marchantia.—Common on wet ground and rocks, or even in drier places among grass in the shade of walls or fences. It

may be recognized by flattish green body about 1 cm. wide and 5–8 cm. long, attached by silky hairs. At some times it bears on the upper surface sessile cups containing green grains, and sends up erect slender sexual branches which spread out into flat heads 6–8 mm. across, some scalloped at edge and some with finger-like rays. When cups or sexual branches are present no other liverwort can be mistaken for it. A very similar one, except in these parts (*Conocephalus conicus*) may be distinguished by its larger size and larger stomata, looking like needle pricks over the surface, while those of *Marchantia* are just visible. It may be used for the vegetative parts. Collect in July. Free from dirt as much as possible, and preserve in formalin or 70% alcohol.

Porella.—Abundant everywhere on the bases of trees especially in low grounds or wet bottom lands. It may be recognized by its dirty-green pinnately branched shoots, 1–2 mm. wide, with crowded overlapping rounded leaves. The plants are always intricately interwoven. Flakes of the bark may be peeled off with a broad knife or chisel, taking care not to tear up the plants into too small patches. Collect in summer. Preserve dry, after drying under light pressure. Some should be kept in formalin or alcohol for demonstration of finer structure of sex organs.

Mnium.—Any species of the genus will do. The commonest species eastward is *M. cuspidatum*. It is abundant everywhere in patches on shady banks and in open woods about the bases of trees. It may be recognized by the yellow or orange oval capsule, thin and irregularly wrinkled when dry, horizontal or pendent on a stalk 2–3 cm. long. The leaves are broadly oval, with fine sharp teeth under lens, and a distinct midrib. When moist the leaves are rather pale green, and not crowded or overlapping. When dry the clump is a dull, dirty green, and the leaves are much curled and twisted, expanding quickly when wetted. The male and female organs are in the same cluster, at the apex of the axis. Under the microscope the species may be recognized by the *orange* inner peristome with double rows of perforations in the membrane below the segments. Preserve as directed for *Porella*. Almost any similar moss will serve equally well, especially the common species of *Bryum*.

Equisetum.—The gametophytes are not readily obtainable. The sporophytes of the common *E. arvense* grows on dry sandy banks, often on railroad embankments. The underground stems send up in spring (April–May) unbranched flesh-colored shoots 5 mm.

in diameter and 10–25 cm. high, with brown scale-like sheaths at the nodes. These shoots terminate in a cone-like cluster of sporophylls. Later in the season from the same underground stems, grow green much branched shoots, looking somewhat like miniature pines, the main lateral axes being produced in whorls at the nodes. Collect both sorts of aerial shoots with underground shoots and roots attached. Preserve the flesh-colored and underground shoots and a few green shoots in alcohol or formalin; most of the green shoots may be dried under light pressure between drying paper or newspaper.

Adiantum.—Gametophytes of any fern will answer. They are flat green heart-shaped bodies 2–5 mm. in diameter, attached to soil by rhizoids. They may be collected on fern pots or grown in greenhouses, or may be obtained from supply company named. Especial care should be taken to have some young sporophytes still attached to gametophytes. The sporophytes of the maidenhair fern are easily recognized by the peculiarly branched leaf. The stem is wholly underground. Each leaf has a slender polished stalk which forks into two equal branches; these fork, one branch of each pair growing straight and bearing leaflets while the other again forks in the same way; and so on until 4–8 branches have been formed on each half. Collect underground stems and roots, loosening them gently and washing off dirt carefully to avoid destroying all root tips and hairs. Preserve these in alcohol or formalin. Gather leaves when the crescent-shaped fruit dots at edges of leaflets are yellowish brown (August). Preserve by drying, spreading out each leaf to show its mode of branching clearly.

Selaginella.—A wild species, *S. rupestris*, grows abundantly on dry bare hills and rocks. It forms grayish-green, much branched tufts, 3–8 cm. high, with narrow bristle-tipped appressed leaves, and resembles in aspect a large rigid moss. Many branches are terminated by a sharply quadrangular spike of sporophylls, about 1 cm. long. Several exotic species are commonly cultivated in greenhouses and window gardens, where they produce sporangia abundantly. Any species will answer. Collect the wild plant about July. Specimens may be preserved dry or in alcohol or formalin.

Pinus.—Any species will answer. The Scotch pine is so widely planted that it is often easiest to collect. The leaves are grayish

green, in pairs, 5–10 cm. long; cones small, about 5 cm. long, the ends of scales bearing a conspicuous protuberance, long and recurved on the basal scales. The Austrian pine, also widely planted, has dark green longer leaves (10–15 cm.), larger cones, with no recurved bosses. The flowers are of two sorts and should be watched for in spring (May) as new shoots appear. The staminate flowers form conspicuous yellow clusters at the base of the young shoots, and should be collected as soon as the sporangia begin to shed the spores. The pistillate flowers are quite inconspicuous, small oval clusters (5–7 mm. long) projecting slightly beyond the tip of the young shoots. The tree bearing staminate flowers usually bears few pistillate ones, and *vice versa*. Collect shoots bearing each kind of flowers, cutting far enough back to include the leaves of the previous year. Preserve in alcohol or formalin. Collect also year-old and two-year-old cones. Preserve the former (green) in fluid; the latter (mature) dry.

Caltha.—This plant is common in wet meadows and swamps northward. It is 15–30 cm. high, smooth, with rather coarse hollow ribbed stems, orbicular or kidney-shaped alternate leaves, with broad clasping base to the petiole, and numerous bright yellow flowers 20–25 mm. in diameter, produced for two weeks or more in April or May. Gather entire plant; wash the roots. Preserve a few plants and an extra supply of flowers and fruits in alcohol or formalin. Dry most of the entire plants.

Lathyrus.—The sweet pea is grown in almost every flower garden and is known everywhere. Preserve flowers and leaves in summer in alcohol or formalin.

Stems.—The various sorts recommended may be collected at any convenient time and preserved in fluid.

Seeds.—The most useful seeds for laboratory work are Indian corn, wheat, buckwheat, castor bean (*Ricinus*), white lupine, (*Lupinus albus*), scarlet runner (*Phaseolus*), broad bean (*Vicia faba*), hemp, white mustard. These should be obtained fresh each year, as they deteriorate more or less with age. Those which cannot be had everywhere (such, perhaps, as lupine, castor bean, scarlet runner, and broad bean) may be purchased of seedsmen in large cities. See advertisements in magazines.

Potted plants.—Such as are grown in window gardens or all greenhouses will suffice. A commercial greenhouse, if accessi-

ble, will raise tomato, castor-bean, bean, and sunflower plants as ordered, and will furnish active young plants at any season required, in case pupils cannot grow them either at school or home.

Malt.—Can be obtained ground or unground at any brewery, or may be made by sprouting barley until the seedlings appear and then drying at about 100° C.

APPENDIX III.

APPARATUS AND REAGENTS.

THE chemicals required are so few that in most cases they may be most conveniently obtained through local dealers. It is desirable, however, to order apparatus from dealers who make a specialty of manufacturing or supplying optical, chemical, and physical apparatus. Schools are entitled to import such apparatus free of duty, and by doing so through importing firms a large part of the cost may be saved. The list is given here for its convenience as a summary. The amounts necessary are not specified as they vary with the size of classes, and the teacher who is prepared to conduct the experiments can readily determine how much is needed.

CHEMICALS.

Acetic acid.—Used for fixing protoplasm.

Alcohol.—Large schools should buy in barrel lots free of revenue tax. For regulations apply to the revenue collector of the district in which the school is situated, or to the Secretary of the Treasury.

Ammonium hydrate (ammonia).

Barium hydrate.—For making baryta water; or this can be obtained fresh as needed from druggist.

Chromic acid.—Used in fixing and decalcifying.

Corn starch.—As prepared for table or laundry.

Formalin.—This is a 40 per. cent solution of formaldehyde in water. Dilute solutions can be prepared as needed. Most plants require a 10 per cent solution, *i.e.*, formalin 1 part, water 9 parts.

Grafting wax.—Made as follows: Melt together resin (by

weight) 4 parts, beeswax 2 parts, tallow 1 part; mix well; pour into a pail of cold water; grease the hands and "pull" till nearly white. In using it should be handled with greased fingers to prevent its sticking to them.

Iodine.—Either solid, from which the tincture can be prepared by dissolving a few flakes in alcohol, or the tincture may be purchased.

Mercury.—For directions for keeping it clean and dry, see *Botanical Gazette* **22**: 471. Dec. 1896.

Paraffin.—A common quality, melting at about 65° C.

Phenolphtalein.—A few grams will last a long time.

Potassic hydrate.—May be bought in sticks and the solution made, but it is more convenient to buy the *liquor potassæ* of druggists.

Sodium chloride.—Table salt is pure enough.

Vaseline.

APPARATUS FOR MORPHOLOGY.

Dissecting microscopes.—Each pupil should be provided with one. A most effective low-priced dissecting microscope was designed by the author and is manufactured by several firms. In no case has the author any financial interest in the instruments. The stand T 1, manufactured by the Bausch & Lomb Optical Co., Rochester, N. Y., with 1-inch lens, and a similar one by Queen & Co., Philadelphia, have been approved by the designer. Many forms offered to schools by jobbers are not worth buying.

Compound microscopes.—The school should be supplied with at least one good compound microscope for demonstrations, and as many more as can be profitably used. If the teacher is capable of using such instruments properly he will be able to select it wisely with such advice as he may obtain from personal acquaintances on whose judgment he can rely. Schools are advised to deal only with manufacturers of established reputation.

Scalpels.—Each pupil should be provided with a sharp knife with slender blade for dissection. It is desirable for the school to furnish scalpels of suitable form. The slender blades, 3–3.5 cm. long on cutting edge, are recommended.

Forceps.—Straight form, with smooth points, will be found useful, though not indispensable.

Needles.—Each pupil should have a pair of needles (No. 6,

sharps) with the eye end set into a soft pine penholder or similar handle. They must be kept sharp on a fine oil-stone.

Drawing materials.—A medium pencil (No. 3 or M) and a very hard one (No. 6 or 6 H) should be used and *kept sharp*. Slips of heaviest linen ledger paper (120 lb.) cut 14 × 8 cm. are recommended. Only one drawing should be put on a slip.

APPARATUS FOR PHYSIOLOGY.

Since much of the apparatus needs to be put together by the student, the requisites are mainly tools and a good supply of tubing, both glass and rubber, bottles, and bell jars. The following will enable the foregoing experiments to be carried out.

Tools.—Hammer, fine saw, three or four chisels, assorted files, brace and assorted bits, screw-driver, smoothing plane, with a supply of nails (especially finishing nails) and screws will be found most useful.

Glass tubing.—A little capillary tubing (0.5 mm. bore) will be needed. Most used sizes are 5 mm. (3 mm. bore), 7 mm. (5 mm. bore.) Some larger sizes (13 and 19 mm.) will also be useful.

Rubber tubing.—3 and 5 mm. bore mostly ; some of 10 and 15 mm. bore.

Bottles.—Wide-mouthed, various sizes, up to 1 liter.

Tumblers.—Jelly glasses answer well. Odd lids and glass dishes from homes and stores can be made useful.

Corks.—Assorted sizes. Several *rubber stoppers*, sizes 8, 10, 12, 3-hole, are desirable.

Bell jars.—Several sizes are necessary ; 15 × 20 and 20 × 30 cm. will be found useful ; also at least one 30 × 50 cm. All should have ground rim and tubulure at top.

Funnels.—Glass, assorted sizes. 6, 8, and 12 cm. diam. are most used ; there should also be two or three larger ones.

Filter paper.—Buy cut filters 15 and 18 cm. in diameter.

Thermometers.—Should be graduated in degrees, $-10°$ to $+100°$ C., with milk-glass scale.

Test tubes.—2 × 15 cm. is a convenient size.

T-*tubes.*—Two sizes, 5 and 10 mm. bore.

Bunsen burners.—If gas is not available, gasolene burners should be substituted.

Marble.—A plate 25 × 25 × 2.5 cm., polished on both sides. It can be re-polished after etching and used as often as desired.

Filter pump.—Can be used if water service is available, or if a head of 5 m. can be secured by tank. Körting's is excellent.

Rulers.—30 cm. long, graduated in millimeters.

Brushes.—Camelhair brush of large size, and sablehair, smallest, are useful.

Pins.

Tin tube.—3 × 15 cm. See experiment 20.

Absorbent cotton.—Also a roll of cotton batting.

Sheet lead.—Light weight, used by plumbers.

Plate glass.—Cut into pieces 20, 25, and 35 cm. square.

Pine sawdust and *clean sand.*—For germinating seeds.

APPENDIX IV.

REFERENCE BOOKS.

The following books will be found useful to teacher or pupil or both, and are recommended as suitable reference books for the school library. The list is not intended to be exhaustive, nor does it include books for popular reading.

FOR GENERAL REFERENCE.

KERNER: Natural history of plants. New York: Henry Holt & Co. $15.00. (Translated by Oliver.)

STRASBURGER, NOLL, SCHENCK and SCHIMPER: Text-book of botany. New York: The Macmillan Co. $4.50. (Translated by Porter.)

BENNETT and MURRAY: Handbook of cryptogamic botany. New York: Longmans, Green & Co. $5.00.

VINES: A student's text-book of botany. New York: The Macmillan Co. $3.75.

SACHS: Lectures on the physiology of plants. New York: The Macmillan Co. $7.00. (Translated by Ward.)

GOEBEL: Outlines of classification and special morphology. New York: The Macmillan Co. $5.50. (Translated by Garnsey and Balfour.)

WARMING: Handbook of systematic botany. New York: The Macmillan Co. $3.75. (Translated by Potter.)

GRAY: Systematic botany. New York: The American Book Co. $2.00.

BESSEY: Botany, *Advanced Course*. New York: Henry Holt & Co. $2.20.

GEDDES: Chapters in modern botany. New York: Charles Scribner's Sons. $1.25.

WARMING: Lehrbuch der ökologischen Pflanzengeographie. Berlin: Gebr. Bornträger. (A German translation by Knoblauch. An English translation is now in preparation.)

PFEFFER: Pflanzenphysiologie. Ed. II., vol. 1. Leipzig: Wilhelm Engelmann. M. 20. (An English translation is now in preparation by Dr. A. J. Ewart.)

VINES: Lectures on the physiology of plants. New York: The Macmillan Co. $5.00.

GOODALE: Physiological botany. New York: The American Book Co. $2.00.

FOR LABORATORY DIRECTIONS.

BERGEN: Elements of botany. Boston: Ginn & Co. $1.10.

SPALDING: Introduction to botany. Boston: D. C. Heath & Co. 80 cts.

MACBRIDE: Lessons in elementary botany. Boston: Allyn & Bacon. 60 cts.

MACDOUGAL: Experimental plant physiology. New York: Henry Holt & Co. $1.00.

ARTHUR: Laboratory exercises in vegetable physiology. Lafayette, Ind.: Kimmel & Herbert. (Pamphlet.) 35 cts.

DARWIN and ACTON: Practical physiology. New York: The Macmillan Co. $1.60.

ARTHUR, BARNES and COULTER: Plant dissection. New York: Henry Holt & Co. $1.20.

APPENDIX V.

OUTLINE OF CLASSIFICATION.

In the foregoing work no endeavor has been made to present any scheme of classification, but only to develop certain principles in logical fashion. As a supplement the following general classification, adapted mainly from Strasburger, Noll, Schenck and Schimper's *Lehrbuch der Botanik*, may be useful in showing the relationship of the more important plants named in the text and appendices.

All classification is more or less artificial. The purpose of such an outline is to indicate roughly the present knowledge of kinship among plants. Even were knowledge perfect it would naturally be impossible to do this in a linear arrangement such as is necessary in a book. Moreover, knowledge is far from complete. It is to be expected, for example, that ultimately botanists will be able to express much more accurately the relationship between the groups of fungi and the algæ than is now possible. Then, the various groups of fungi will be ranked alongside the green plants to which they are most akin, as is now done in the Schizophyta, instead of being constituted a class by themselves.

The following classification differs more or less from all others in details. Like them, it is merely tentative, and will be modified as knowledge increases. Only in the most general divisions will all schemes be found similar.

Subkingdom I. THALLOPHYTA. Thallophytes.

Class I. **Myxomycetes.** Slime molds.

Class II. **Schizophyta.** Fission plants.

Order 1. *Schizophyceæ.* Fission algæ. Blue-green algæ.
Nostoc. Rivularia. Oscillaria.

Order 2. *Schizomycetes.* Fission fungi.
Bacteria.

Class III. **Diatomeæ.** Diatoms.

Class IV. **Peridineæ.** Often ranked as animals.

Class V. **Conjugatæ.** Brook silks and desmids.

Spirogyra. Zygnema. Mesocarpus. Desmids.

Class VI. **Chlorophyceæ.** Green algæ.

Order 1. *Protococcales.*

Pleurococcus. Volvox.

Order 2. *Confervoidales.* Confervoid algæ.

Ulothrix. Cladophora. Ulva.

Order 3. *Siphonales.*

Vaucheria. Caulerpa. Acetabularia.

Class VII. **Phæophyceæ.** Brown algæ.

Order 1. *Phæosporales.*[1]

Lessonia.

Order 2. *Fucales.*[1]

Fucus. Sargassum.

Order 3. *Dictyotales.*

Class VIII. **Rhodophyceæ.** Red algæ.

Orders numerous. Polysiphonia.

Class IX. **Characeæ.** Stoneworts.

Chara. Nitella.

Class X. **Hyphomycetes.** True fungi.

A. Phycomycetes. Algoid fungi.

Heterogamous Series.

Sub-class I. *Oomycetes.*

Orders numerous. Cystopus.

Isogamous Series.

Sub-class II. *Zygomycetes.*

Orders numerous.

Mucor. Rhizopus. Empusa.

B. Mesomycetes. Intermediate fungi.

Sporangiate Series.

Sub-class III. *Hemiasci.*

Yeast.

Non-sporangiate Series.

Sub-class IV. *Hemibasidii.*

Brand fungi. Smuts.

C. Mycomycetes. Higher fungi.

Sporangiate Series.

Sub-class V. *Ascomycetes.*

Witch-broom fungus. Mildews. Truffles. Penicillium. Cup-fungi. Morels.

Non-sporangiate Series.

Sub-class VI. *Basidiomycetes.*

Rusts. Cap-fungi. Polyporei. Puff-balls.

Class XI. **Lichenes.** Lichens.

Physcia. Theloschistes.

[1] Various larger species known as tangles, kelp, rock-weed, bladder-wrack.

Subkingdom II. BRYOPHYTA. Bryophytes. Mossworts.

Class I. **Hepaticæ.** Liverworts.
Order 1. *Ricciales.*
Riccia.
Order 2. *Marchantiales.* Liverworts.
Marchantia. Lunularia.
Order 3. *Anthocerotales.* Horned liverworts.
Order 4. *Jungermanniales.* Leafy liverworts. Scale mosses.
Porella.
Class II. **Musci.** Mosses.
Order 1. *Sphagnales.* Peat mosses.
Sphagnum.
Order 2. *Andreæales.*
Order 3. *Archidiales.*
Order 4. *Bryales.* True mosses.
Bryum. Mnium. Hypnum.

Subkingdom III. PTERIDOPHYTA. Pteridophytes. Fernworts.

Class I. **Filicineæ.**
Order 1. *Filicales.* True ferns.
Adiantum. Pteris. Aspidium. Asplenium.
Order 2. *Hydropteridales.* Water ferns.
Class II. **Equisetineæ.** Horsetails. Scouring rushes.
Equisetum.
Class III. **Lycopodineæ.**
Order 1. *Lycopodiales.* Ground pines.
Lycopodium.
Order 2. *Selaginellales.* Club mosses.
Selaginella.

Subkingdom IV. SPERMATOPHYTA. Seed plants.

Class I. **Gymnospermæ.** Gymnosperms.
Order 1. *Cycadales.* Cycads.
Cycas.

Order 2. *Coniferales.*

Pines, spruces, larches, firs, etc.

Order 3. *Gnetales.*

Welwitschia.

Class II. **Angiospermæ.** Angiosperms.

Sub-class I. *Monocotyledones.* Monocotyledons.

Orders several. Lilies, irises, grasses, sedges, rushes, palms.

Sub-class II. *Dicotyledones.* Dicotyledons.

Orders numerous. Most herbs with net-veined leaves, deciduous shrubs and trees.

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